THE UNIVERSITY
OF MICHIGAN
JUN 23 1960
ENGINEERING
LIBRARY

Number 6
June, 1959

ИЗМЕРИТЕЛЬНАЯ
ТЕХНИКА

SOVIET INSTRUMENTATION AND
CONTROL TRANSLATION SERIES

Measurement Techniques

(The Soviet Journal *Izmeritel'naya Tekhnika* in English Translation)

■ This translation of a Soviet journal on instrumentation is published as a service to American science and industry. It is sponsored by the Instrument Society of America under a grant in aid from the National Science Foundation with additional assistance from the National Bureau of Standards.

SOVIET INSTRUMENTATION AND CONTROL TRANSLATION SERIES

Instrument Society of America Executive Board

John Johnston, Jr.
President
Henry C. Frost
Past President
Dr. Ralph H. Tripp
President-Elect-Secretary
Thomas C. Wherry
Dept. Vice President
Glen G. Gallagher
Dept. Vice President
Adelbert Carpenter
Dept. Vice President
Nathan Cohn
Dept. Vice President
John C. Koch
Treasurer
Nelson Gildersleeve
Dist. I Vice President
Charles A. Kohr
Dist. II Vice President
John R. Mahoney
Dist. III Vice President
George L. Kellner
Dist. IV Vice President
Milton M. McMillen
Dist. V Vice President
Glenn F. Brockett
Dist. VI Vice President
Thomas H. Pierson
Dist. VII Vice President
John A. See
Dist. VIII Vice President
Robert C. Mann
Dist. IX Vice President
Joseph R. Rogers
Dist. X Vice President
John J. McDonald
Dist. XI Vice President

Headquarters Office

William H. Kushnick
Executive Director
Charles W. Covey
Editor, ISA Journal
George A. Hall, Jr.
Assistant Editor, ISA Journal
Herbert S. Kindler
Director, Tech. & Educ. Services
Ralph M. Stotsenburg
Director, Promotional Services
William F. Minnick, Jr.
Director, Public Relations

ISA Publications Committee

Nathan Cohn, *Chairman*
Jere E. Brophy, Enoch J. Durbin, George R. Feeley, Richard W. Jones, George A. Larsen, Thomas G. MacAnespie, John E. Read, Joshua Stern, Frank S. Swaney, Richard A. Terry

Translations Advisory Board of the Publications Committee

Jere E. Brophy, *Chairman*
T. J. Higgins, S. G. Eskin, G. Werbizky

■ This translation of the Soviet Journal *Izmeritel'naya Tekhnika* is published and distributed at nominal subscription rates under a grant in aid to the Instrument Society of America from the National Science Foundation. This translated journal, and others in the Series (see back cover), will enable American scientists and engineers to be informed of work in the fields of instrumentation, measurement techniques, and automatic control reported in the Soviet Union.

The original Russian articles are translated by competent technical personnel. The translations are on a cover-to-cover basis, permitting readers to appraise for themselves the scope, status, and importance of the Soviet work.

Publication of *Izmeritel'naya Tekhnika* in English translation started under the present auspices in August, 1959, with Russian issue No. 1 of Jan.-Feb. 1958. The six issues of the 1958 volume year were published in English translation by February, 1960. Russian issue No. 1 of January, 1959 was published in March, 1960, and the twelve issues of 1959 will be published in English translation by December, 1960.

Transliteration of the names of Russian authors follows the system known as the British Standard. This system has recently achieved wide adoption in the United Kingdom, and is being adopted in 1959 by a large number of scientific journals in the United States.

All views expressed in the translated material are intended to be those of the original authors, and not those of the translators, nor the Instrument Society of America.

Readers are invited to submit communications on the quality of the translations and the content of the articles to ISA headquarters. Pertinent correspondence will be published in the "Letters" section of the ISA Journal. Space will also be made available in the ISA Journal for such replies as may be received from Russian authors to comments or questions by American readers.

1959 Issue Subscription Prices:

Per year (12 issues), starting with 1959, No. 1

General: United States and Canada	$25.00
Elsewhere	28.00
Libraries of nonprofit academic institutions:	
United States and Canada	$12.50
Elsewhere	15.50
Single issues to everyone, each	$ 6.00

1958 issues also available. Prices upon request.

See back cover for combined subscription to entire Series.

Subscriptions and requests for information on back issues should be addressed to the:

Instrument Society of America
313 Sixth Avenue, Pittsburgh 22, Penna.

Translated and printed by Consultants Bureau Enterprises, Inc.

Number 6—June, 1959

English Translation Published June, 1960

Measurement Techniques

The Soviet Journal Izmeritel'naya Tekhnika in English Translation

Reported circulation of the Russian original 3,000.

Izmeritel'naya Tekhnika is an organ of the Academy of Sciences, USSR

EDITORIAL BOARD
as Listed in the Original Soviet Journal

G. D. Burdun, *Editor*
I. I. Chechik, *Asst. Editor*
V. O. Arutyunov
N. M. Karelin
B. M. Leonov
M. I. Levin
V. F. Lubentsov
P. G. Strelkov
B. M. Yanovskii
M. K. Zhokhovskii
N. I. Zimin

See following page for Table of Contents.

Copyright by Instrument Society of America 1960

MEASUREMENT TECHNIQUES

1959, Number 6 June

CONTENTS

	PAGE	RUSS. PAGE
Introduction of Advanced Measurement Techniques and Instruments for the Automatization of Control and Regulation of Industrial Processes – an Important Task of the National Economy	391	1
For the Further Development of Methods and Devices for the Automatization of Technological Control in Machine Construction. A.I. Yakushev	395	5
On the Economic Analysis in Designing Electric Measurement Instruments. A.S. Konson	400	9
Linear Measurements		
Instruments for the Control of Kinematic Accuracy of Linkages and Machine Tools. B.A. Taits and V.P. Korotkov	406	12
A Device for Calculating the Clearance between the Crankshaft Journal and the Crankcase Bushing. L.M. Itsykson and G.L. Reizina	410	16
Checking Squares of Over 500 mm by Simple Devices. V.I. Nikolaev	412	17
A Precision Microscope for the Measurement of Small Dimensions. V.E. Kostin	412	18
Application of an Optical Inner Base Range Finder in a Factory Arrangement for Checking Dimensions of up to 25 m. B.E. Kostich	413	19
Mechanical Measurements		
Measurements of Pressures Defined by the Relation $P = P_0 + p(t)$ for $p(t) \ll P_0$. R.G. Karpov	416	21
Determination of Static Characteristics of a Force-Compensation System Containing an Elastic Tube. M.Kh. Lantsman	421	25
An Adapter for Mechanical Pressure Indicators. Yu.N. Gogin	427	29
A Revolution Counter. I.P. Lishchinskii	428	30
A Deflection Meter. A.M. Startsev	429	31
Electrical Measurements		
On the Relation between Static and Dynamic Characteristics of High-Voltage Semiconductor Rectifiers. K.B. Karandeev and N.G. Alfer'eva	430	32
A Visual Method of Determining the Nonlinearity of Sawtooth Voltage. D.I. Ataev	435	35
Measurement of Impedances at Audio Frequencies by the Method of Magnetically Coupled Circuits. O.G. Malkina	440	39
Measurement of Angle Errors of Mutual Inductance Coils by Means of an Alternating Current Bridge. A.Z. Veksler	445	42

CONTENTS (continued)

	PAGE	RUSS. PAGE
On Using Silicon Stabilitrons for the Production of Standard Voltage. S.D. Dodik	448	45
Measurements at High and Super-High Frequencies		
Stepping Up the Input Resistance of Semiconductor Amplifiers. G.N. Novopashennyi and P.V. Novitskii.	454	49
Consideration of Multiple Internal Reflections in the Investigation of Complex Transmission Lines Composed of Super-High-Frequency Units. K.I. Palatov	457	51
Measurement of the Quality Factor of Cavity Resonators with Small Damping. E.I. Kulikov	462	55
Liquid and Gas Flow Measurements		
The Location of Average Velocity on the Vertical in Free Water Flow. G.V. Zheleznyakov	466	58
Discharge Coefficients of Diaphragms and Nozzles. S.S. Kivilis	469	60
Essays and Reviews		
Measuring Instruments at the Twelfth Exhibition of Chemical Instrumentation "Akhema 1958." E.N. Belikov.	474	64
Information		
Problems in Measurement Automation Discussed at the Intercollegiate Scientific Conference	478	67
From the National Committee of the USSR for Automatic Control	481	69
Book Reviews		
A.V. Ervais: Adjustment and Repair of Opticomechanical Measuring Instruments, Mashgiz, Moscow, 1958, 458 pp., 237 illus., 8000 copies. L.N. Timoshenko.	482	70
Material Received by the Editorial Board		
An Automatic Device for the Prevention of Overloading of Oscillograph Vibrations in Tensometric Measurements. G.E. Dukhovnyi	484	71
Mechanization of the Stamping of Weights. A.S. Poroshin	485	72
A Simplified Method of Checking Truck Scales. L.T. Dzyuman.	486	72
Recording of Results of State Inspection of Measures and Measuring Instruments. A.L. Suvorov	487	73
Committee on Standards, Measures, and Measuring Instruments		
From the Council of Experts of the Committee. N.I. Evstyushin.	488	74
Measures and Measuring Instruments Approved by the Committee According to State Inspection Results and Authorized for Use in the USSR	491	76

INTRODUCTION OF ADVANCED MEASUREMENT TECHNIQUES AND INSTRUMENTS FOR THE AUTOMATIZATION OF CONTROL AND REGULATION OF INDUSTRIAL PROCESSES – AN IMPORTANT TASK OF THE NATIONAL ECONOMY

Our country has entered a new phase in its historical development – a period of advanced development of a Communist society.

The resolutions of the Twenty-First Congress of the Communist Party of the USSR outlined a grandiose program of Communist development, the fulfillment of which is connected with further progress in all branches of science, technology, and culture, and a rise in the living standard of the Soviet people.

The resolutions adopted at the Congress emphasized the primary importance of industrial development, further technological progress, introduction of mechanization and automatization, specialization, and coordination of production.

In his address at the Twenty-First Congress of the Communist Party of the USSR, Comrade N.S. Khrushchev said: "The goals of the Seven-Year Plan can be attained only by wide application of new technology, complex mechanization and automatization of industrial processes, and specialization and cooperation in all branches of the national economy."

Instrumentation and measurement techniques will play an important role in the realization of the grandiose program outlined in resolutions adopted at the Congress.

The introduction of new advanced technology, complex automatization, and mechanization is impossible without modern and accurate measuring instruments and measurement methods. Standardization, accuracy, and the correct application of measures and measuring instruments are indispensable in the organization of modern industrial production.

Instrumentation provides the means for the automatization of control and regulation of industrial processes in the national economy.

According to figures provided by the Seven-Year Plan, the production of instruments in 1965 will increase 2.5 to 2.6-fold with respect to the 1958 output.

During the last few years, our country has achieved considerable success in the development of instrumentation and measurement techniques. The accuracy of measuring instruments and of standard equipment received for checking tests improved, new and improved standards for various kinds of measurements were created, the range of measurements was increased, a number of automatic instruments were constructed, and instrumentation became one of the leading branches of the national economy. Many specialized instrumentation plants produced instruments for linear, mechanical, thermic, and electrical measurements, instruments for automatic control and regulation of technological processes, for determining the composition of substances, electronic measurement equipment, and others.

However, the nomenclature and the number of produced measuring instruments, as well as their quality, still cannot satisfy the growing needs of our national economy. Along with first-class equipment, the users are supplied with a certain quantity of obsolete equipment which does not come up to modern technological standards. The mass production of some indispensable instruments, in particular, of accurate standard measuring instruments, has still not been organized. A large number of instruments for active dimension control in work on metal-cutting

lathes are necessary for the automatization of technological processes in machine construction. The Standardization Bureau of the Committee of Standards, Measures, and Measuring Instruments developed a series of such instruments securing the automatic adjustment of grinders while operating with electrical-contact, inductive, and pneumatic detectors. The application of these instruments on surface, cylinder-and-cone, and internal grinders increased their efficiency by 20%.

However, the widespread use of these devices for production control is limited by the production capacity of the City Councils of National Economy in Khar'kov, White Russia, Saratov, Leningrad, and Moscow, which are responsible for the manufacture of measuring instruments.

The automatization and mechanization of control of finished products have a considerable economic effect. A single automatic control device takes the place of three to five inspectors. Centralized production of standardized parts for automatic control systems (data transmitters, stabilizers, filters, electronic units, relays, and others) will facilitate production, reduce the costs of construction and finishing, and speed up the introduction of such systems in industry. Standard units can be applied in all mass-production machine construction enterprises.

The production of new models of instruments for the control of gear meshing is of great importance in the national economy. Low quality of gears, not detected in production due to the lack of measuring instruments, leads to noise, irregular operation, low accuracy, and short life of gear transmissions. Plants producing tooth measuring instruments are, at the present time, still not familiar with the production of highly accurate instruments (provided with electrical and optical components) and especially those for the control of large-size and small-modulus gears.

Weighing is widely applied in various branches of the national economy. In railway transport, box cars, containing loads such as ores, coal, etc., are weighed statically on ordinary lever scales (with stopping on the scales), which is time-consuming. However box cars in motion can be weighed with almost the same accuracy by means of electrotensiometric scales, which would reduce the weighing time 40 to 50-fold, and, consequently, would permit greater turnover of box cars. Similarly, in shipping, the freight loaded or unloaded by cranes is not weighed, or, it is weighed by means of ordinary lever scales, which slows down the loading and unloading. The application of spring or electrotensiometric scales with remote reading and recording mechanisms in cranes would permit weighing while the crane is in motion, which would greatly increase efficiency.

The Ministry of Communications of the USSR should take the necessary measures for the wide application of railway electrotensiometric scales and the Ministry of the Merchant Fleet of the USSR, the Ministry of the Fresh Water Fleet of the RSFSR, and the organizations controlling fresh water shipping in other republics should strive for the soonest installation of modern crane scales.

The Gor'kii State Control Laboratory for Measurement Techniques developed a number of original standard dynamometers of the Tokar' model for the measurement of forces in the range from 10 kg to 2000 t with an error of less than 0.5%. These dynamometers were favorably received by industrial workers and officials in the control of machines and instruments for the mechanical testing of materials. The demand for these dynamometers is many times greater than their annual production.

The Councils of National Economy in Moscow and Latvia should fully satisfy the demand for these dynamometers.

It is also necessary to organize the mass production (by the Tomsk Council of National Economy) of electrotensiometric dynamometers for the measurement of large forces, developed by the Scientific Research and Construction Institute for Testing Machines, Instruments, and Mass Measuring Instruments (NIKIMP) of the Moscow City Council of National Economy.

A few years ago, an automatic device for the sorting of parts according to hardness was developed in this institute. The model of this instrument was demonstrated at the All-Union Industrial Exhibition; however, its mass production, which can be achieved, for instance, in the Krasnodar Council of National Economy, has still not been organized.

The control of a number of new technological processes and the development of scientific research are impossible without accurate pressure measurement methods. Precision instruments for the measurement of pressure with an accuracy to 0.1% are necessary for the calibration of all kinds of pressure gauges, of which millions are produced each year. Industry produces precision pressure gauges for measurement ranges from 60 to 2500 kg/cm^2.

It is necessary that industry start the production of accurate piston pressure gauges for low pressures (up to 2.5, and up to 6 kg/cm^2) developed by the All-Union Scientific Research Institute of the Committee of Standards, Measures, and Measuring Instruments.

New instruments for high-temperature measurements of up to 6000°C in metallurgy, power engineering, rocket and nuclear engineering, and a number of other fields, are the most important prerequisites for the improvement of the quality of production and automatization of technological processes.

New models of instruments for high-temperature measurements, which have been developed in recent years, have been custom-built.

The mass production of the following instruments has still not been organized: portable optical pyrometers OPK-57, designed for temperature measurements in plants and laboratories; photoelectronic color pyrometers TsÉP-3, for the continuous control of high-temperature processes in metallurgy; photoelectric pyrometers FOTOPIR-S1, used in rolling mills; and photoelectric control pyrometers ARS-52, for the automatic temperature regulation in hardening tanks.

Accurate standard pyrometers (OP-48M and ÉOP-51M) for high-temperature measurements, developed by the Khar'kov State Institute of Measures and Measuring Instruments, which were to be produced by the L'vov Council of National Economy plants, are still not being mass-produced. The Kaluga Council of National Economy, entrusted with the production of these instruments, must secure their industrial production in the shortest possible time.

The industrial production of standard temperature lamps developed by the D.I. Mendeleev All-Union Scientific Research Institute of Metrology should be organized in plants of the Moscow Council of National Economy.

Domestic industry produces a great number of instruments for electrical measurements at higher frequencies. The plants for electrical-measurement instruments in Leningrad and Krasnodar organized the production of accurate electric meters which were developed by metrologic institutes of the Committee of Standards, Measures, and Measuring Instruments. However, the mass production of prototype models has still not been organized.

Instruments for the accurate calibration of a number of electronic measuring instruments are still not being produced in sufficient quantity. This lowers the quality of adjustment of electronic apparatuses and complicates their servicing. The State Committee for Radio Engineering must organize the mass production of a set of standard equipment for electronic measurements, developed by the All-Union Scientific Research Institute of Physicotechnical and Electronic Measurements of the Committee of Standards, Measures, and Measuring Instruments.

Instruments of the differential-transformer type, a number of which have been already designed, are of the greatest importance for the automatization of control. These instruments, permitting the remote reading of data, recording, and automatic regulation of controlled parameters, are widely applied in the most diversified branches of industry. As the components of these instruments are not standardized – in the first place, converters and amplifiers – data transmitters and secondary units are not interchangeable, which causes serious difficulties in assembly and adjustment. The plants of the Moscow, Leningrad, L'vov, and Armenian Councils of National Economy, which produce these components, should correct this serious deficiency.

Along with problems in securing the production of the corresponding nomenclature, the quality of measuring instruments produced by industry is also of great importance.

The Committee of Standards, Measures, and Measuring Instruments and the institutes and laboratories of the Committee maintain a systematic quality control of measuring instruments produced by instrumentation plants, and a study of instruments in use is also in progress.

As a result, it was established that the quality of a number of mass-produced instruments does not satisfy the requirements of national economy and technological standards. A number of instruments are characterized by instability of readings, short life, and a low quality of the external finish.

The quality of instruments for the measurement of pressure, vacuum, flow, and level, and automatic regulators whose sensitive elements consist of pressure gauge tubes, membranes, and bellows, is especially low. The instability of readings of instruments in use and their short life are a consequence of insufficient familiarization with the technology of production processes in the manufacture of sensitive elements and the wrong choice of raw materials.

A study of the situation in the use of instruments produced by the Pressure Gauge Plant of the Tomsk Council of National Economy indicated that a considerable number of instruments became unserviceable in three to five months.

The quality of instruments produced by the plant "Teplokontrol'" of the Tatarsk Council of National Economy, and of automatic electronic potentiometers and automatic electronic bridges produced by the plant "Manometr" of the Moscow Council of National Economy, is also unsatisfactory.

The quality of instruments and devices for linear measurements should be greatly improved with respect to their durability. Individual measuring instruments (plane-parallel length standards, indicators, micrometers, etc.) become quickly unserviceable, which causes an unjustified increase in the demand for these instruments in the national economy.

The quality of chart paper for recording instruments, produced by the plant "Poligrafist" of the Rospromsovet (Leningrad), is not satisfactory with respect to the quality of the paper itself, as well as the quality of print, and does not satisfy the required standards. This is one of the reasons for the lower accuracy in the recording of readings of self-recording measuring instruments, and constitutes the obstacle to the improvement of their design (operational speed and the chart speed).

The production efficiency and technological discipline should be greatly improved in a number of instrumentation plants.

The institutes of the Committee of Standards, Measures, and Measuring Instruments are still not paying enough attention to the metrologic service of automatized control and automation of industrial processes. The work "Investigation of Methods for the Transmission of Linear Dimensions in Automatic Lines and Some High-Accuracy Automatic Lathes," which has been organized by the D.M. Mendeleev All-Union Scientific-Research Institute of Metrology, does not correspond to the assigned theme. It is necessary that the problems of metrologic service in automation and control of industrial processes occupy the main attention of the institutes of the Committee and state control laboratories for measurement techniques.

The further development of instrumentation is, to a certain extent, slowed down by the insufficient production capacity of plants. In correspondence with resolutions adopted at the Twentieth Congress of the Communist Party of the USSR, new instrumentation plants are under construction throughout the country. The most important task of workers in instrumentation industry is a vast increase in the production of instruments, which should be brought about by the reconstruction and expansion of existing enterprises and better use of existing facilities.

Individual instances of inaction and indifference regarding the introduction of new advanced instruments and methods of measurement and cases of production of low-quality instruments are intolerable, especially when viewed against the background of the great advance of Soviet metrology and instrumentation.

The resolution of the Central Committee of the Communist Party of the Soviet Union, calling for a plenum on June 24, 1959, was published in May; this session was devoted to problems connected with the fulfillment of resolutions adopted at the Twenty-First Congress on the introduction of complex mechanization in industry and construction, automatization of production, introduction of assembly lines, substitution of obsolete equipment, dies, instruments for the further development of industrial production and construction, improvement of the quality of products, and reduction of production and construction costs.

Instrumentation and metrology workers are responding to the appeal of the June Plenum of the Central Committee of the Communist Party of the USSR by their active participation in the replacement of obsolescent equipment by improved equipment, by introducing new and advanced measurement techniques, and by the overall automatization and mechanization of production, as outlined in the resolutions of the Twenty-First Congress of the Communist Party of the USSR.

FOR THE FURTHER DEVELOPMENT OF METHODS AND DEVICES FOR THE AUTOMATIZATION OF TECHNOLOGICAL CONTROL IN MACHINE CONSTRUCTION

A.I. Yakushev

The historical task of reaching and surpassing the economically most advanced capitalist countries in per-capita production in the period of the full development of Communist society, as outlined at the Twenty-First Congress of the Communist Party of the USSR, can be successfully fulfilled only by introducing over-all mechanization and automation in production.

The automatization of industrial processes and the qualitative improvement of products are impossible without the automatization of methods and means for the technological control in all branches of the national economy.

The present state and the directions of further development of automation were considered in a special section of the Third All-Union Conference on Automatization of Industrial Processes, which was held from May 12 to 16, 1959. One hundred-twenty scientists and engineers from Moscow, Leningrad, Khar'kov, Gor'kii, Sverdlovsk, Chelyabinsk, Riga, and other towns of the Soviet Union took part in the conference. Twenty-three reports dealing with problems in design, construction, and introduction of automatic control devices in machine construction were heard and discussed at the Conference. E.R. Dvoretskii (of the Standardization Bureau of the Committee of Standards, Measures, and Measuring Instruments) announced that SB developed and production-tested models of instruments for the production control of cylinder-and-cone, surface, internal, and centerless grinders. However, regardless of the highly developed design, these instruments have not received the attention they deserve.

SB continues work on the improvement of existing and the creation of new data transmitters, securing the control with errors less than 0.2 μ, not only in grinding, but in gear-cutting, thread-cutting, shaping, and other operations. SB is also working on the design of automatic control units, measuring pulse counters for the control of kinematic displacements, and methods for quick conversion of automatic control devices for other measurements.

Work on the standardization of measuring units, creation of standard adapters for mechanized control, standardization and universalization of automatic control devices with the aim of reducing the cost of their centralized production and simplifying the design and construction work, which is planned by SB, was unanimously approved. Other works planned by SB in the field of automation (automation in computing temperature corrections in control, reduction of inertness of pneumatic systems, and many others) were also of great interest.

Ya.I. Tseitlin (of the Leningrad Tool Plant – LIZ) announced that in ten years the plant personnel had produced hundreds of automatic devices based on mechanical, electromechanical, photoelectric, photoelectronic, pneumatic, and other methods of transformation of measuring pulses for the control and sorting of races of ball- and roller-bearings, balls, cylindrical and conical rollers, and other parts, into groups according to their different parameters.

The automatic devices produced by LIZ are used in all ball-bearing plants and in a number of plants of other branches of industry in the USSR and the Peoples' Democracies.

The majority of types of automatic devices produced by LIZ are manufactured in batches of a few tens of pieces: for instance, automatic devices for the rejection of ball-bearing races faulty with respect to height and nonparallelism of end faces, devices for the rejection of ball-bearing races faulty with respect to the outside diameter or nonperpendicularity of the outside surface axis with the end face of the ring devices, for the rejection of cylindrical rods faulty with respect to length, etc.

From among the automatic devices produced by the plant and used in industry, the following automatic control devices can be mentioned as examples of greatest interest with respect to purpose, construction, and efficiency.

The selective control automatic devices 25AK and 26AK are designed for sorting into eighteen groups the

outer and inner races of radial one-row ball-bearings with respect to the rolling path diameter. The nominal tolerance of races in a group after the final sorting is equal to 2 μ, and in preliminary sorting, 0.02 mm.

The capacity of these automatic devices is equal to 1200 sorted races per hour. The characteristic feature of these automatic devices is the application of a new multirange photoelectric detector, based on the "opticator" mechanism. In operation, the errors of the detector do not exceed 0.5 μ. The compactness and the simplicity of the detector, its stability in operation, and its comparatively small size, offer great possibilities for its use in most diversified automatic measuring devices.

The photoelectronic automatic device for the inspection for surface defects of steel balls, rather than visual inspection, also should be mentioned. The automatic device was awarded Honorable Mention at the Brussels World's Fair, and it will be exhibited at the Soviet Exhibition in New York in 1959.

The automaton rejects balls with cavities, scratches, spots, and other defects on their surface. The device operates on the basis of the principle of reflectometry, and its capacity is equal to 6000 balls per hour.

The FÉU-19M photomultiplier is used as the sensitive element.

Beside means of passive automatic control, LIZ produces means of active control (for instance, electrical-contact detectors for groove-grinders produced by the Il'ich plant).

The production of automatic control devices in the LIZ plant has been continuously rising, and the production in 1958 increased threefold in comparison with production in 1952.

I.N. Khaskin and A.Ya. Peliks (of the OKB of the Moscow Council of National Economy) imparted their experience in creating and introducing devices for the automatic control of large-size products, produced on automatic assembly lines, and they also described devices for automatic angle measurements.

The automatic device for the control of railway car axles on the assembly line, which will be used in the Uralvagonzavod plant, and other automatic devices were used as examples to demonstrate the convenience of automation in the inspection of parts weighing up to 400 kg, of a diameter up to 200 mm, and a length of up to 1800 mm, where 25-30 parameters are to be checked.

The output in the inspection of such parts can be equal to 400-1200 parts per shift, with measurement errors not exceeding 8-10% of the tolerance for the dimension controlled.

In order to secure a high accuracy in the inspection of large-size parts, it is necessary to apply automatic systems for the compensation of temperature errors in measurements.

Devices for the printing of cards where the inspection results will be recorded are used in recent models of automatic control devices. A conventional marking of the parameters according to which a part is rejected will be automatically stamped on rejected parts. In order to improve the quality of automatic control devices, OKB has developed and successfully applied a special method for the inspection of automatic devices after they are finished and tested in operation.

OKB came to the conclusion that the main emphasis in the design of automatic control devices should be placed on the creation of standard models designed on the basis of standard units and components, providing the possibility of controlling different products by means of special adapters.

Works by OKB in the field of the automatization of angle measurements are of great interest. An inductive dial-gauge (proposed by G.M. Brodskii and S.S. Podlazov) by means of which the error in angle measurements can be reduced to 4-2" and less, where the measurement procedure is automatized, has been designed and tested in the Bureau.

For running angular measurements (in motion) a direct current feed circuit for the gauges has been developed by OKB. The indicated gauges are applied in devices designed by OKB, serving for the automatization of angle measurements in the control of kinematic accuracy of lathes, in manufacturing divider discs, dials, and precision gears, for the adaptation of gear-cutting mills, etc.

The report by Yu.M. Reznikov on the automatization of control at the First State Bearing Plant (GPZ) was received with great interest.

At the present time, over 200 different automatic control and sorting devices and over 800 devices for

production control are used in this plant. Devices for automatic sorting of balls, rollers, and rings into dimension groups have been applied to a great extent even before the war, but the devices for production control have been widely used only since 1948-1950, and the automatic devices for the acceptance control only since 1957-1958.

It should be remarked that automatic control at GPZ is being introduced not only in mechanical departments, but also in other shops (for instance, in the forge for the control of diameters of rolled races) and in assembly plants (for instance, for the control of eccentricity of races in bearings and in the measurement of radial clearances).

The application of automatic control devices in the plant substituted for the work of more than two thousand inspectors and saved about fifteen million rubles per annum.

However, even this plant has to perform a great task in improvement and wider application of automatic control.

Scientific principles for the design of measuring instruments based on the application of the latest achievements in mechanics, physics, mathematics, and other sciences are being studied in our country. Studies of measurement errors in automatic control, of methods of increasing the accuracy and efficiency of control, etc., are also in progress.

The report by G.G. Baranov was devoted to problems in the automatic accuracy control in centerless grinding. The author developed methods of increasing the operational accuracy of these grinders on the basis of theoretical analysis and a vast amount of experimental data.

In his report, M.I. Kochenov discussed the basic problems in accuracy of the automatic control of dimensions in machine construction. The author has developed the theoretical principles for methods of increasing the accuracy and efficiency in automatic control, analyzed the possibilities and scope of application of multiple control, proposed systems for the adjustment of automatic devices, securing a considerable reduction of the amount of "spurious" waste, analyzed the accuracy of means for the adjustment of automatic devices, and set forth recommendations for increasing the accuracy of these means.

The report by A.K. Kutai considers the mathematical principles underlying the selection in the feedback of automatic production control and the method of determining the statistical characteristics of various feedback systems; references for the selection of the width of suppressor bands, volume of selections (in continuous as well as selective measurements) and others, are also given.

The method of calculating these systems is based on the theory of probability and is corrected according to statistical data on the operation of fourteen automatic assembly lines of high efficiency.

The theoretical basis for the adjustment of controlling and measuring automatic devices was considered in the report by Kh.B. Kordonskii.

In connection with the increased application of sorting and controlling automatic devices, it is necessary to develop sufficiently simple and practical methods for their certification. One of these methods could be the method of two standards, or of two adjustments, which the author based on inverse Laplace functions. The method provides the possibility of establishing the maximum measurement error by the sorting of two standards (or of one standard, but, for two adjustments).

The method proposed in the report has been widely applied in the automatic production of instrument parts.

The report by S.N. Sokolov substantiated the advisability of applying selective control by means of automatic control devices, built into automatic lines.

The report by O.B. Balakshin was devoted to the problem of designing pneumatic measuring devices for automatic control units. In automation, the application of pneumatic measuring devices operating at high pressure, provided the possibility of performing the simultaneous measurement of a considerable number of dimensions in not readily accessible places, with a parallel performance of some calculating operations, for instance, in measuring the average dimensions of a part with the aim of eliminating the influence of eccentricity of bodies of revolution as well as of displacements of the part in its measuring position due to unavoidable clearances on the measurement results, in measuring the deviation from a given form (conical, oval), etc. The methods of computing the parameters of pneumatic measuring devices, permitting an increase in accuracy, were considered in the report.

Reports by V.S. Vikhman (NIÉL), N.M. Rodigin, I.E. Korobeinikova, and others dealt with methods of conversion of measuring pulses.

Works performed in NIÉL toward the creation of devices for the automatic dimension control, based on the application of television in combination with quick-action electronic computers, were of great interest.

The work performed in NIÉL showed that this method is particularly efficient in the automatic inspection of parts of complex shape, permitting the construction of universal readily modified automatic control devices of high accuracy and high efficiency.

In one of the developed and experimentally tested automatic control devices (designed by V.S. Vikhman), based on the application of the kinescope in combination with a photocell and an electronic computer, the part to be inspected is placed between the screen of the electron-beam tube (kinescope) and the photocell.

The electron beam of the kinescope moves reciprocally in the vertical direction with a frequency of the order of 50 cps and simultaneously moves in the horizontal direction at a frequency of the order of 1 cps.

A moving, luminous spot, which is in the given case used as a light source, appears on the phosphor surface of the kinescope.

An optical system is placed between the kinescope screen and the part, by means of which the rays emitted from the kinescope are focused in the form of a light spot on the plane passing through the cross section of the part. The movement pattern of this light spot is geometrically similar to that of the luminous spot of the phosphor, but reduced by a suitable factor (from 10 to 500).

Moving vertically in the downward direction in the control plane, the luminous point is, at the beginning, outside the part and illuminates the photocell. At the moment when the beam strikes the part, the illumination of the photocell is interrupted; thus, a current jump appears in the external photocell circuit, which is transmitted to the input of the pulse generator. From the pulse generator output, the pulse is transmitted to a two-place binary electronic computer.

The principle of inspecting a part by means of this device consists in the following.

A thin transparent plate with two fine nontransparent curves is fitted snugly to the screen of the kinescope. One of these lines, on a corresponding scale, marks the upper limit, while the second marks the lower limit of tolerance for the given part.

The light beam emitted from the kinescope must be interrupted twice in its vertical motion and, correspondingly, creates two pulses at the electron counter input. If the part under inspection is suitable, the figure 10 is composed; if the dimension of the part exceeds the upper tolerance limit at this section, the figure 01 is composed; if the dimension of the part is below the lower tolerance limit at this section, the figure 11 is composed.

An intermediate electromagnetic relay, securing the corresponding action of the terminal unit of the automatic control device, is connected to the anode circuits of thyratrons.

Devices for the control of various treatments of surface layers of parts have been developed by a team under the direction of Yu.K. Grigulis in the Institute of Machine Design, Academy of Sciences, Latvian SSR. The operation of these devices is based on the characteristics of propagation and penetration of high-frequency electromagnetic currents. The devices provide the possibility of measuring the geometric parameters of parts, determining the physical properties of the surface layer of parts (electrical conductivity and magnetic permeability) and controlling different surface layers or coatings by means of a small-size (of a diameter of 3-8 mm) data transmitter operating remotely from the device. One of such devices is an apparatus providing the possibility of measuring the displacement of a metallic part for an initial clearance of 0.75-1 mm with an accuracy of 0.5 μ, where the range of displacements to be measured is equal to 0-200 μ. The device can be successfully applied as a production control instrument in polishing, honing, etc.

A device with semiconductors, designed for the measurement of thicknesses of various coatings on steel or nonconducting base layers and of nickel coatings on any base layer, with errors ranging from 3 to 5% and a measurement range of 0-50 μ, also should be mentioned.

In their report, N.M. Rodigin and I.E. Korobeinikova (of the Institute of Metal Physics, USSR Academy of Sciences, Sverdlovsk) gave an account of the great possibilities and various measuring instruments based on the application of eddy currents.

Instruments based on this method are successfully applied for the quality control of heat-treatment, depth of the cemented or decarbonized layer, electrical conductivity, external and internal defects (for instance, non-fusion, cavities, slag impurities), and also the nonuniformity in the wall thickness of tubes, etc.

A most valuable advantage of the eddy current method is the fact that the control operation is performed almost instantly, without damaging the product and, usually, without touching it with any part of the instrument.

As a result of discussions on reports and communications the conference adopted a resolution which can be summarized as follows.

In the field of automatic control, definite results in the theoretical field as well as in the manufacture of a large number of automatic control devices, production control devices for grinding processes, and others, which are in use, have been achieved by the domestic machine construction industry.

At the same time, the quality of measuring instruments and control methods does not satisfy the modern requirements of complex and automatized production which is under development.

Automatic inspection is mainly applied for the control of part dimensions and is not sufficiently developed for the control of physical quality parameters of parts and conditions of manufacturing processes.

The underestimation of the importance of control, automatized control included, leads to the production of finished products of lower quality, which reduces the lifetime and the reliability in operation of machines and instruments and hinders cooperation in industry.

The disparity between the efficiency in machining operations and control operations led to great expenditures for the maintenance of control equipment which did not prevent considerable losses due to waste and faulty production.

The basic direction in the development of control in modern domestic machine construction should aim at the attainment of such a state where the quality control, being the indispensable element of the technological system of production, will direct the industrial processes according to results obtained by the measurement of quality characteristics of parts and components.

Under these conditions, the complexity of control of all quality parameters must be achieved on the basis of automatic control.

In their resolution, the participants in the conference noted that the instruments for the directing (active) control are the tools for increasing the stability of work processes and the efficiency of all personnel in a factory. These instruments create the possibility of applying selective interoperation acceptance control. The introduction of such instruments must take place simultaneously with a whole complex of measures for the rationalization of the acceptance control system.

The introduction of higher technological standards for the automatic control in machine construction must be based on a wide application of recent physicotechnical principles of conversion of measuring pulses. In particular, it is necessary to use television, high-speed electronic computers, electromagnetic high-frequency circuits, radioactive isotopes, ultrasound, and others, by taking into account the special operating conditions of control devices in automatic lines and units.

One of the most important tasks is the improvement of accuracy, reliability, and stability in operation of automatic control devices. The necessary condition for this is a vast improvement in quality of standard automatic equipment produced by industry (electronic, optical, etc.).

It is necessary that the State Planning Commission of the USSR and the Committee of Standards, Measures, and Measuring Instruments outline the development of unified and standardized units and components of automatic control devices for their centralized production in planning the work of subordinate institutes and construction bureaus, after having done the necessary work for the standardization of these units.

The resolution adopted at the conference called on the State Planning Commission of the RSFSR to secure the mass production of standardized units for control-sorting automatic devices (data transmitters, relays, stabilizers, filters, command-apparatuses, and others) in order that they can be put on the market, and also to secure the supply of necessary equipment for the automatized control in machine construction.

It is necessary that the State Scientificotechnical Committee coordinate the most important projects in the construction, design, and experimental research phases in the field of technical measurements in machine construction and also provide technical information on the achievements in automation, by publishing, in particular, catalogs of measuring devices in machine construction.

The view expressed at the conference was that the development of scientific research work in the field of automation should be intensified, including the development of highly efficient and accurate automatic control devices, the development of scientific principles for the selection of optimum fields where various forms of automatic control should be applied, and the application of statistical control methods, computation of technico-economical efficiency of automatic control, etc.

It is necessary to secure a greater number of engineers graduating in the field of instrumentation and automation and improve the training of these specialists.

It is desirable that the councils of national economy of main economic regions organize, in 1959-1960, special courses to provide constructors, technologists, and inspectors with higher qualifications in the field of automatic control.

The conference resolved to ask the State Planning Commission and the GNTK of the USSR and the Committee of Standards, Measures, and Measuring Instruments to organize at the Standardization Bureau a permanent exhibition of instruments and automatic devices for the control of dimensions in machine construction, supplementing it with the newest models manufactured at home and abroad, along with suitable drawings.

The participants in the conference indicated that the metrological supervision of modern devices for the automatic acceptance and governing control on the part of the local organs of the Committee of Standards, Measures, and Measuring Instruments is a necessary measure at the present time.

ON THE ECONOMIC ANALYSIS IN DESIGNING ELECTRIC MEASUREMENT INSTRUMENTS

A.S. Konson

The construction of electrical instruments is one of the branches of Soviet machine construction which is developing at a particularly fast pace.

At the present time, all machine construction enterprises strive for the development of machines, instruments, and apparatuses which would be the most economical in the world. The economic analysis in designing is of great importance for the solution of this problem. In his report to the Twenty-First Congress of the Communist Party of the USSR, Comrade N.S. Khrushchev emphasized the necessity for determining the economic efficiency of technical solutions.

The economic analysis should determine the possibilities for further improvement of operational characteristics and constructional efficiency of the instruments designed as well as the possibilities for the reduction of time necessary for their mastering. The economic analysis in designing helps in the selection of the best variant. It is instrumental in introducing improvements in instrument design which would provide the necessary results with less effort. Therefore, every project for an electric measurement instrument of a new design must be completed by an analysis determining whether its introduction in industry is economical, and all the basic technical solutions embodied in projects must be substantiated from a viewpoint of economy.

At the present time, the economic analysis in designing electric measurement instruments is in its initial stage. Even with respect to devices which are used as tools in industrial operations, the analysis of the economic soundness of introducing them in industry is still rarely performed. Even where such analysis is done, a number of serious mistakes occur. Thus, the calculation and the comparison of the yearly output of devices are sometimes

forgotten when devices of different design are mutually compared. In a number of cases, the analysis is limited to the calculation of capital investment, and the operational costs are not calculated and compared. In the construction of electrical instruments, the operational costs sustained by the user are still not being determined when the instrument design is analyzed.

The amortization period of additional capital investments created by savings on operational costs is still not always taken as a criterion of economic efficiency in introducing an electric measurement instrument of a new type. This index should be calculated in those cases where the new instrument is more expensive than the one previously used, but would bring savings in operational expenditures. The time in which the instrument will pay for itself is calculated according to the formula

$$\tau_{2/1}=\frac{K_2-K_1}{C_1-C_2} \text{ years,}$$

where K_1 and K_2 are capital investments, i.e., the costs of the compared variants of the instrument ($K_2 > K_1$); C_1 and C_2 are the operational costs for the compared variants of the instrument, rub/year ($C_2 < C_1$); $\tau_{2/1}$ is the amortization period for additional capital investment; this investment is incorporated in the second variant of the instrument, the operational costs of which are lower than those of the first variant.

The second variant of the instrument will be better than the first if

$$\tau_{2/1}<\tau_n$$

where τ_n is the norm for the amortization period of the additional capital investment.

Norms for amortization periods of additional capital investments established in 1956 are used at the present time. In electrical engineering industry, the norm is six years.

We shall demonstrate the application of this criterion by evaluating the economic basis for introducing an instrument for the measurement of three electron tube parameters operating under dynamic conditions.

The calculation of expenditures showed that the net cost of the projected instrument was equal to K_{ad} = = 1700 rub. The use of this instrument would effect a yearly saving in operational costs equal to:

$$\Delta L_3 = 1.13\ P\ (t_1-t_2)\ q_2 \quad \text{rub./year,}$$

where ΔL_3 are savings on industrial wages (with additional charges); P is the hourly rate of pay according to the wage scale for workers performing the measurement of tube parameters; t_1 is the time norm for the measurement of parameters of one tube by the graphical method, hr; t_2 is the time norm for the measurement of parameters of one tube by means of the instrument, hr; q_2 is the yearly output of the projected instrument expressed by the number of electron tubes tested by means of this instrument.

The factor 1.13 takes into account additional wages and charges for the wages of social insurance workers.

For P = 2.25 rub/hr (for the class IV), t_1 = 20 min, t_2 = 2 min, and $q_2 = 30 \cdot 8 \cdot 307 = 73680$ pieces per annum* ΔL_3 = 5600 rub per annum.

If the expenditures for the upkeep of the instrument (including major repairs) in the amount of Δa_{ad} = = $0.1 \cdot 1700$ = 170 rub per annum are deducted from these savings, the net savings on operational costs will be equal to:

$$\Delta C_3 = \Delta L_3 - \Delta Q_{ad} = 55830 \text{ rub./year.}$$

The amortization period of the additional capital investment in the projected instrument, created by savings on operational costs, will be equal to:

*The work shift time and all other data pertain to the year when the calculation was made.

$$\tau = \frac{\Delta K_{ad}}{\Delta C_s} = \frac{1700}{55830} = 0{,}03 < \tau_n = 6 \text{ years},$$

which indicates that its use is financially very advantageous.

Beside direct savings in the operation of the projected instrument, indirect savings also should be determined: savings due to reduction of waste as a result of using the new measuring instrument and due to improvement of production quality, efficiency, etc.

Along with savings on operational costs of the projected instrument, the yearly savings due to a reduction of the initial cost of the instrument, capital expenditures in organizing its production, and the respective amortization periods should also be taken into account:

$$t_{am\cdot p} = \frac{S_{1ce} - S_{2ce}}{(S_{2in} - S_{1in})\, n},$$

where S_{1ce} and S_{2ce} are the capital expenditures for the design and production of each variant of the instrument; S_{2in} and S_{1in} are the net costs of each variant of the instrument; n is the yearly output.

One of the most important deficiencies in the operation of many plants which produce electric measurement instruments is the high cost of instruments, which is due to their high initial cost. The prices of many instruments are still very high. One of the reasons for this is the fact that, in designing electric measurement instruments, not enough attention is being paid to the economic analysis of technological efficiency in producing these instruments.

All too often the designers of electric measurement instruments forget that the design of the majority of components must be determined on the basis of lowest production costs. An analysis of the amount of material (according to weight and cost of material) and the amount of work necessary for the production of instruments will make it possible to single out those units and components which contribute most to the over-all cost. Unfortunately, such analyses are not often performed in construction bureaus.

Hardly any data are available on the analysis and calculation of economic efficiency secured by the standardization of units and parts and on the production of series of scaled instruments. Approximate calculations, based on empirical data on the production time with respect to the weight of geometrically similar parts, are little used in the preliminary determination of net production costs of newly designed instruments.

We shall demonstrate one of the possible methods of approximate calculation of costs involved in the production of projected instruments. Each part of a projected instrument is matched with the geometrically most similar part which has been manufactured before, the production time (t_0) of which is known. The production time of parts manufactured earlier should be translated into norms for the current year. If this part was last manufactured in the k-th year, and the time norm for its production was t_k, the time norm for its production for the current year can be approximately determined as

$$t_0 = \frac{t_k}{\lambda},$$

where λ is the factor indicating the increase of the production norm for similar items during the period from the k-th year to the current year.

The production time for each part of the newly designed instrument (t_1) can be approximately determined according to the equation

$$t_1 = t_0 \left(\frac{G'_0}{G_0} \right)^{2/3} \text{ norm-hours},$$

where t_0 is the production time of a geometrically similar part which was produced earlier; G'_0 and G_0 are the net weights of geometrically similar parts – of the newly designed (G'_0), and of the earlier (G_0).

The greatest difficulties are encountered in the economic analysis of new types of electric measurement

TABLE 1

Comparison of Respective Performances of the Instruments Compared

Characteristic	New instrument	Old instrument
Measurement error, %	5	6
Maximum frequency of the process measured, cps	800-900	700
Maximum current amplification factor	Over 100	30
Possibility of operation with wire- as well as induction receivers	Can operate with both	Can operate with wire receivers only
Possibility of quick detection of defects	Provided	Not provided
Possibility of varying the bridge voltage	Voltage variation provided (4, 6, 12 v)	Bridge voltage fixed
Calibrating the receiver without observing the light spot of the oscillograph	Provided	Not provided
Amplifier operation without special feed stabilizer for tube-heating circuits	Provided	Not provided

TABLE 2

Comparison of Technological and Economic Characteristics of a Projected Instrument with Those of the M61 Instrument

Characteristic	Projected instrument	Instrument M61
Current	Direct	Direct
Instrument class	4.0	4.0
Use	On panels	On panels
Range of operating temperatures, °C	−50 to +50	−25 to +60
Measurement range, v	150	150
Moment of rotation,	$17 \cdot 10^{-7}$	$90 \cdot 10^{-7}$
Quality factor	0.5	1.8
Weight of movable part, in g	0.22	0.21
Dimensions, mm	30 x 30 x 45	37 x 43 x 28
Instrument weight, g	62	100
Form of damping	By magnetic induction	By air
Resistance to mechanical disturbances	Shock- and vibration-proof	Shock- and vibration-proof
Power consumption, mw	150	450
Wholesale price, rub	15	26
Length of working part of scale, mm	19	24.5

instruments for use in laboratories of scientific research institutes. The development of economic analysis methods for laboratory instruments has been very slow. In a number of cases, there are no objects which could serve for a comparison when such instruments are designed. However, sometimes the number of the variants compared is artificially reduced by comparison with instruments based on the same physical principle. However, in economic analysis, it is not necessary that the physical principles on which the instruments compared are based be the same. What is required is the uniqueness of those parameters which can be measured by means of the above-mentioned instruments with an adequate accuracy. Along with a comparison of different operational parameters of laboratory instruments, expenditures with respect to their production and operation should be taken into account in the final analysis of the design quality.

Usually, the requirements for high-quality operational parameters of new instruments involve high costs. As a rule, in new types of equipment, high-quality operational parameters attainable at small costs are required. Therefore, in those cases where any operational parameter of the more expensive variant of the new instrument, the cost of which cannot be estimated, has a higher value, it is convenient to calculate the index of relative advantages due to the improvement of any operational parameter of the new instrument with respect to the additional cost:

$$\epsilon = \frac{\Delta E}{\Delta C},$$

where ΔE is the improvement of the instrument parameter in percentages with respect to its former value; ΔC is the increase in cost due to the improvement of this parameter in percentages with respect to its former value.

Let us consider some examples from design practice.

In designing a batch of measuring mechanisms with magnets placed inside a frame, the question of the most suitable magnet shape arose. Two variants were considered: a round and a cut magnet.

The advantage of the second variant is the fact that it permits a reduction in the shunting of the magnetic flux due to the cuts at the end. However, this variant requires an additional grinding of two surfaces, whereby the production time is increased by approximately 30%. Laboratory tests showed that, in the case where a round magnet is used, the induction in the gap varies by only 5% (from 0.138 to 0.145 wb/m^2), which is of no practical importance in the given case. Moreover, the time required for the production of the magnet is considerably increased. Thus, the index of the relative advantage gained by additional costs $\epsilon = 0.05:0.3 = 0.167$. Therefore, as a result of the analysis, a round magnet was chosen.

Table 1 shows data on operational advantages of a projected instrument for the measurement of quickly fluctuating pressure exerted by water on the walls of a channel model.

Moreover, the new instrument has another advantage – a higher stability of the "zero point," which is important in the measurement of slow processes.

As the new instrument has four amplification channels and the old one three, the cost of one channel was determined with respect to the compared variants. Calculations showed that the cost of one channel for the new instrument is 56 rub higher than the cost of a channel for the old instrument. This is a small fraction of the cost of a channel in the old instrument. Thus, in the given case, a considerable improvement of operational characteristics of the instrument is achieved by a slight increase in its production cost. This indicates that the adoption of the projected instrument can be considered as financially sound.

For an economic evaluation of a projected magnetoelectric voltmeter with a movable magnet, Table 2 provides a comparison of its technical and economic characteristics with those of the magnetoelectric voltmeter M61 with a movable frame (the characteristics are arranged in the order of their importance).

It is clear from Table 2 that the projected instrument has considerable advantages over the M61 instrument: it has a greater range of operating temperatures, a smaller size and weight, lower power consumption, and costs less. The cost of the instrument was reduced due to the application of advanced technological processes and simpler assembly of instruments with a movable magnet in comparison with those having a movable frame.

The designers of electrical instruments do not pay enough attention to such important economic factors as, for instance, the cost of the instrument versus its accuracy, measurement range, and other operational character-

istics. Also, not enough attention is paid to the question of who will use the instruments and how large is the demand. However, all this considerably influences the production costs.

Many designers, researchers, technologists, economists, and planners in plants producing electric measurement instruments do not fully grasp the criteria and methods used in determining the economic efficiency of technical solutions. A study of these problems and a systematic exchange of latest experience in the field of economic analysis in designing electric measurement instruments should be organized in plants and in scientific research institutes.

The fact that the last wholesale price lists for materials, equipment, etc. were published in 1955 and have not been revised since cannot be considered as normal. Therefore, at the present time, the wholesale prices of products are at great variance with the production costs. This situation calls for a periodical revision of wholesale prices with the aim of reducing the prices and making them more realistic. In order to enable the designers to carry out the economic analysis in designing electric measurement instruments, they should be provided with manuals indicating the technicoeconomic characteristics and containing wholesale price lists. The compilation of such manuals is an important task for the Economic Research Section of the All-Union Scientific-Research Institute of Electric Measurement Instruments. The obsolete characteristics in these manuals should be systematically replaced by new ones. It is necessary to provide a consistent generalization of the experience in economic analysis gained in designing different kinds of electric instruments and to develop new and improved methods for the solution of design problems. The All-Union Scientific-Research Institute of Electric Measurement Instruments together with the most important plants which produce electric instruments should lead in the solution of these problems.

The improvement of economic analysis in the design of electric instruments will facilitate the expeditious production and introduction in the national economy of instruments of the most economic design.

INSTRUMENTS FOR THE CONTROL OF KINEMATIC ACCURACY OF LINKAGES AND MACHINE TOOLS

B.A. Taits and V.P. Korotkov

In a considerable number of mechanisms, a rigorous coordination between the rotation of the driving and the driven links is required, where the discrepancy must not exceed a few seconds of angle or a few microns and, sometimes, even fractions of seconds or microns. Consequently, the necessity arises for the construction of instruments for precision control of individual links (gears, worm-gears, screws, etc.) as well as instruments for the inspection of entire chains in mechanisms and machine tools.

The results of parametric inspection of gears, screws, etc. cannot provide the possibility of obtaining the over-all characteristic of operational accuracy of a given part in the mechanism, since the individual errors add up and multiply or compensate each other. Therefore, the most accurate parts must be checked under conditions similar to those found in operation, where the complex inaccuracy of a part as revealed in operation is determined.

On the other hand, even the results of the complex inspection of a part cannot provide the over-all accuracy characteristic of the kinematic chain of the mechanism of which this part is a component. Due to an accurate assembly of parts, the over-all inaccuracy of the mechanism often appears to be less than expected.

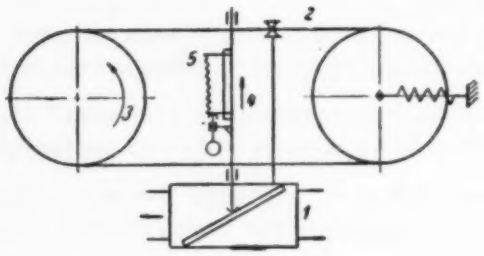


Fig. 1.

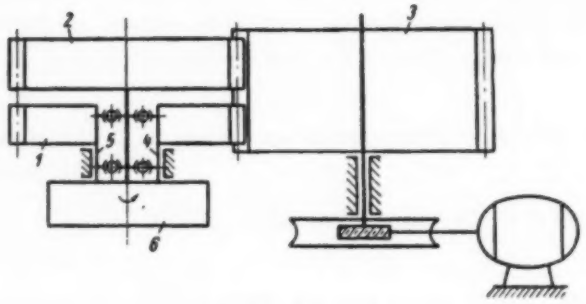


Fig. 2.

The advantage of complex methods in the inspection of parts does not consist only in the establishment of the over-all inaccuracy of a gear or lead screw but also in a considerable reduction in inspection time, the possibility of mechanizing and automatizing the control devices, and also in the convenience of using the inspection results for the compensation of the inaccuracies detected.

A number of instruments where the kinematic principle is used in the control of inaccuracies in gear meshing has been constructed in the USSR.

The MT-2 instrument, where the complex inaccuracy in the single-profile meshing of gears is detected by means of a measuring rack, is available for the control of the complex inaccuracy of gears of a small modulus (from 0.2 to 1 mm).

The device (Fig. 1) consists of a slider 1 with a sinusoidal ruler, belt transmission 2, a fixed disc 3 and a transverse slider 4 with a holder for rack 5. The rack 5 is set in motion by the gear under inspection with which

it meshes along a single profile. The motion of rack 5 with respect to slider 4, which is caused by gear inaccuracy, is registered by an indicator with divisions equal to 0.002 mm. For the adjustment of the device, depending on the pitch diameter of the gear under inspection, the sinusoidal ruler is turned through a certain given angle.

The over-all errors in inspection by means of this device do not exceed 5 μ for a full turn of the gear, and 2-3 μ for cyclic errors.

For the complex single-profile inspection of gears with a medium modulus in mass production, a simple device with a short and reliable kinematic chain has been developed.

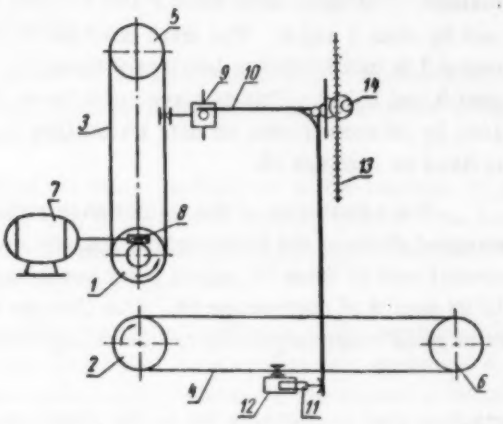


Fig. 3.

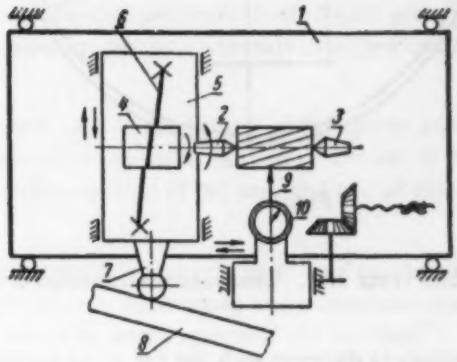


Fig. 4.

The device (Fig. 2) is designed for the inspection of gears with a modulus from 1 to 8 mm and a center distance of 70-300 mm. The measuring gear 1 has the same geometric parameters as the gear 2 to be checked. Both gears mesh with an intermediate gear 3. The rotation of the inner axle 4 with respect to the outside hollow axle 5 acts on the electrical-induction data transmitter 6. From the data transmitter, the current is fed to a self-recording instrument plotting the diagram of the single-profile inaccuracy of the gear under inspection. The recording device has several transmission ratios where 1 mm on the chart corresponds to 1, 2, 4, or 8 sec. The recording range is 200 mm.

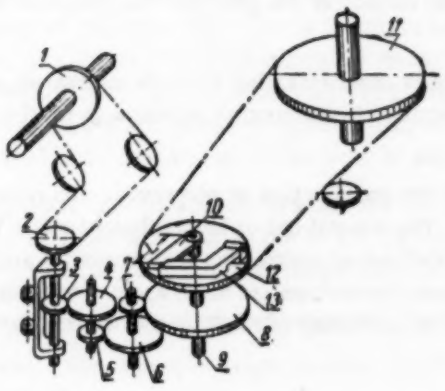


Fig. 5.

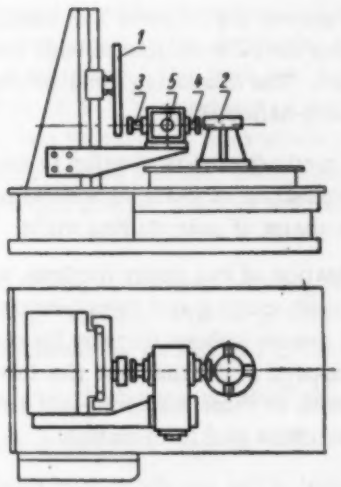


Fig. 6.

It is important to note that the inaccuracy of the intermediate gear does not influence the accuracy of instrument readings if the inaccuracy is constant along the length of each tooth.

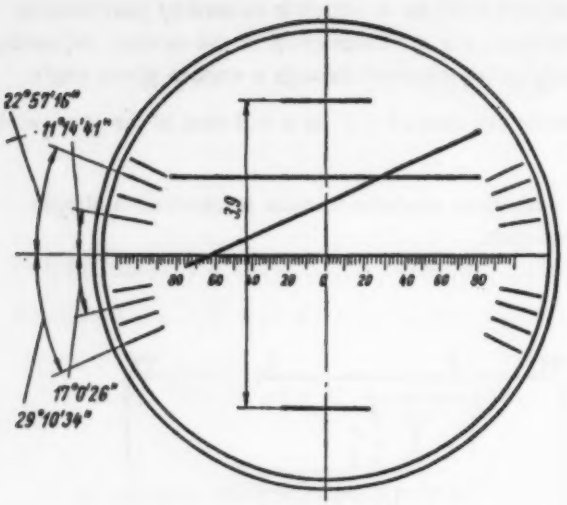


Fig. 7.

Tests performed on the device showed that its errors, combined with those of the recording device, were equal to 2-4" for different transmission ratios.

A universal instrument of the lever-belt type was constructed for the complex single-profile inspection of spur gears of medium moduli. The kinematic layout of the device (Fig. 3) consists of discs 1 and 2 to which the pair of gears under investigation is fixed in a coaxial manner. The discs drive belts 3 and 4 which are kept taut by discs 5 and 6. The drive provided by electric motor 7 is transmitted to carriage 9 through a worm-gear 8 and belt 3. This carriage holds lever 10 which acts, by its second arm, on data transmitter 11, which is fixed on carriage 12.

The adjustment of the transmission ratio of the standard chain of the instrument is done by moving the pivotal axis of lever 10, which is set according to scale 13 by means of microscope 14. This changes the length of the second lever arm. The transmission ratio of the pair of gears under inspection can be changed from 1:3 to 3:1.

Attempts to dispense with the use of an accurate measuring gear in checking led to the development of the standard-free inspection method which has been proposed by N.N. Markov. Such an instrument consists of an evolute meter and an angle pitch gauge, the combination of which permits the plotting of error curves for all right-hand and left-hand tooth profiles. The outside contour of the diagram obtained characterizes the curve of single-profile inaccuracies of the gear, providing the possibility of readily establishing which of the teeth will operate at the section where the profiles overlap.

A pitch gauge proposed by B.A. Taits has been developed for the inspection of the helix line of helical gears. The device is designed for the inspection of gears of diameters up to 300 mm, moduli from 1 to 8 mm, and a helix pitch from 180 mm to infinity. It consists of a bench 1 with two headstocks with front 2 and back 3 mandrels (Fig. 4). A transverse carriage 5 moves on the bench and, through belt 6, transmits the motion to roller 4, which is coaxially mounted on the front mandrel 2.

As table 1 moves, the follower 7 of carriage 5 moves along the sine ruler 8 and sets the roller 4 and the gear which is being tested in motion through belt 6. With a given pitch, these two motions create the helical motion of the gear. The measuring pin 9 touches the side surface of the gear and the gauge 10 registers the deviations of the tooth helical line.

Inspection methods tend to develop in the direction of mechanization and automatization of instruments controlling the production of gears, as well as in the direction of constructing instruments for the accuracy control of kinematic chains of gear-cutting mills.

The coordination of two rotary motions, as well as the coordination of progressive and rotary motions must be controlled in tooth-cutting and thread-cutting mills. The control has to be continuous while the kinematic chain of the mill rotates without stopping for readings. Methods of controlling the kinematic accuracy of machine tools requiring stoppage of the machine (for instance, where theodolites are used) are not suitable for testing precision machine tools, as these methods yield a considerable scattering of readings and do not characterize the accuracy of the machine tool in operation.

For the control of the coordination of rotary motion in precision gear-cutting mills, L.A. Arkhangel'skii and G.I. Tkachevskii constructed a special instrument – a kinematometer. The kinematometer consists of three basic parts: a data transmitter, an indicator, and an amplifier.

The operation of the data transmitter disc is not affected by the eccentricity caused by faulty machining or installation in the machine tool, which is of primary importance in the control of precision machine tools.

The indicator consists of a cylinder with a threaded through opening; its operation is based on the stroboscope principle.

In using the kinematometer for large machine tools, depending on their adjustment, a scale division can be equal to 2" and even 1". The error of the method does not exceed $1\frac{1}{2}$ of a division.

A friction disc instrument proposed by A.V. Levashev is used in a number of machine tool plants for the control of rotation coordination of two links of a kinematic chain.

In the instrument (Fig. 5), the rotation of disc 1 which is mounted on the mill mandrel, is transmitted to disc 2 by means of a belt. The rotation is transmitted to axle 9 and lever 10 by means of friction discs 3, 4, 5, 6, 7, and 8. Disc 11 driving disc 12 with the data transmitter 13 is mounted on the mill bench.

A mismatching in the kinematic chain of the mill will cause a displacement of lever 10 with respect to data transmitter 13.

By means of this instrument, cyclic inaccuracies of a machine tool can be registered with great precision. However, cumulative inaccuracies of worm gears in machine tools are not as accurately detected as by means of a kinematometer.

One of the main deficiencies of the majority of instruments used in the control of kinematic accuracy of mechanisms and, in particular, in the control of the coordination of progressive and rotary motion, is the necessity for using standard kinematic pairs and mechanisms for the reproduction of the assigned law of motion and its comparison with the actual law.

The complexity and high cost of the production of standard parts, kinematic pairs, and mechanisms, and also the limited field of their application, prevent the wide use of such instruments and necessitate the production of instruments and methods for the control of kinematic accuracy where standards are not used.

V.P. Korotkov developed a method for controlling the coordination of progressive and rotary motion in gear-cutting and thread-cutting mills where no standards are used, which is based on the optical coincidence and comparison of velocities of scale marks on the driving and on the driven links of the kinematic chain under inspection.

The basic feature of this method when used in checking the feed chain of gear-cutting mills where the work axis is vertical, consists of the following: a glass ruler 1 (Fig. 6) with equally spaced marks (for instance, every 1 mm), which is illuminated by a light beam, is connected to the progressively moving support of a gear-cutting mill. A line mark 2 on the glass surface, which is also illuminated by a directed light beam, is provided on the turning table of the mill.

On the fixed part of the frame, between the mill carriage and the table, an optical instrument is mounted, with its one objective 3 directed to the scale of ruler 1, and its second objective 4 to the mark 2 at the moment when the mark passes through the longitudinal plane of the mill. The image of the horizontal line of ruler 1 falls into the field of view of ocular 5 where the vertical mark 2 also is projected. The lines are projected in such a way that the image of the ruler line is set at a certain angle (within 10-30°) with respect to the horizontal image of mark 2. Thus, at a certain moment during the control process, two intersecting lines which are constantly moving in the field of vision can be seen (Fig. 7). If the progressive motion and the rotation are accurately coordinated, the lines on the screen move together with an equal velocity and the point of intersection of the lines stays on the vertical cross-hair in the ocular field of vision.

If the progressive motion and the rotation are not coordinated, one of the lines will lag behind and the intersection point of the two lines will move to the right or to the left. The shift will be greater than the actual lead or lag of the line due to the optical magnification of the instrument, as well as due to the slope of the line.

Readings are taken every time the horizontal line coincides with the horizontal cross hair.

With the available objective magnification of 3.9 x, a scale division corresponds to 2, 3, 4, or 5 μ for angles shown in Fig. 7.

Tests showed that the variation of readings does not exceed one division on the screen scale. The over-all error in checking the mill feed mechanism does not exceed ± 5 μ.

Control methods where no standards are used, which are based on the optical coincidence of lines, can also be used for the inspection of thread-cutting lathes, lead screws, etc. For this, instead of a line mark, a dial with equally spaced divisions along the circumference can be placed on the rotating part.

The described instruments for the accuracy control of linkages and machine tools and, especially, the method without standards provide for a high-accuracy control of the kinematic accuracy of gears, lead screws, and kinematic chains. However, modern requirements for highly accurate kinematic chains necessitate a further improvement of these control instruments.

A DEVICE FOR CALCULATING THE CLEARANCE BETWEEN THE CRANKSHAFT JOURNAL AND THE CRANKCASE BUSHING

L.M. Itsykson and G.L. Reizina

The method of selecting the bushing in order to obtain a certain given clearance between the bushing and the crankshaft journal is used in many machine construction plants.

In the selection of bushings, the wall thickness is usually determined according to the equation

$$T=\frac{D_c-D_s-\Delta}{2},$$

where T is the wall thickness of the bushing 1 (Fig. 1); D_c is the mean diameter of the crankcase bedding 2; D_s is the mean diameter of the crankshaft journal 3; Δ is the clearance between the bushing and the journal.

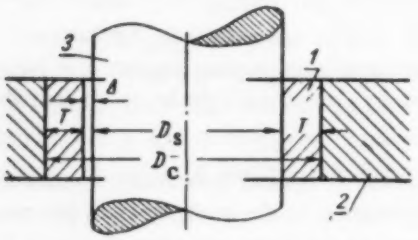


Fig. 1.

Such calculations take much of the worker's time and require trained personnel.

The described device which has been developed by N.I. Endrzhevskii facilitates a quick determination of either the clearance for a given thickness of the bushing, or of the bushing wall thickness for a given clearance with an accuracy of 0.001 mm for D_c and D_s given on the marking plate.

The device (Fig. 2) consists of two connected discs 1 and 2 with dial plates. The discs are held together by screw 3, whereby it is possible to rotate the inner disc about the center or to fix the discs in a certain position with respect to each other.

The dial faces with scales are photostats of dials drawn on tracing paper.

The dial faces can be interchanged for various values of D_c, D_s, T, and Δ. The scales are designed according to the following principle.

It follows from the given equation that any difference $D_c - D_s$ is always equal to the sum $2T + \Delta$. Consequently, if the difference becomes smaller or greater, 2T also decreases or increases by the same quantity (for a constant Δ).

The problem consisted of finding a mutual arrangement of the four scales of the instrument and a matching – in pairs – of scales for which this relation remained valid.

It was solved in the following manner: D_c on the outside disc and D_s on the inner disc have a common angle scale where the diameter values increase counterclockwise on both discs.

When the outer disc is held in a fixed position and the inner disc is rotated clockwise, we obtain an increase of the difference $D_c - D_s$ for a given constant value of D_c. When the inner disc is rotated counterclockwise, this difference decreases.

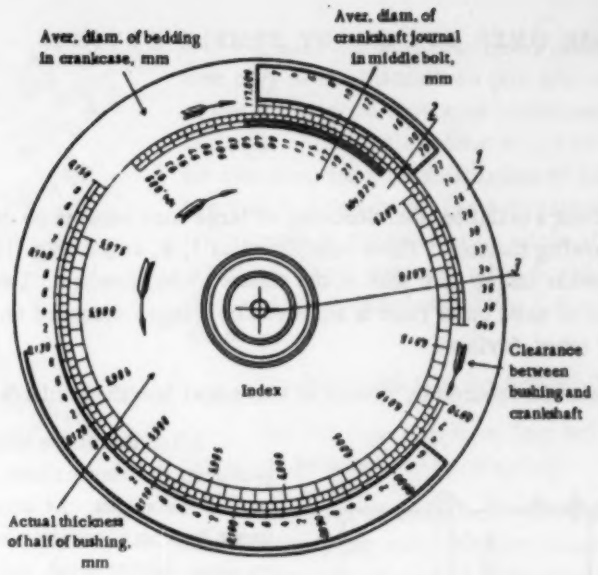

Aver. diam. of bedding in crankcase, mm
Aver. diam. of crankshaft journal in middle bolt, mm
Clearance between bushing and crankshaft
Index
Actual thickness of half of bushing, mm

Fig. 2.

The values on the outer disc Δ scale and the values on the inner disc T scale increase in opposite directions and are on a scale which makes it possible to obtain directly T instead of 2T, i.e., the T scale is twice as large as the angle scale Δ.

Δ increases in the clockwise direction, and T in the counterclockwise direction.

When the inner disc is rotated clockwise, i.e., when the difference $D_c - D_s$ increases, we obtain either an increase in T for any matched pair of Δ and T division marks if Δ remains constant, or an increase of Δ for a constant T.

If the inner disc is rotated counterclockwise, i.e., if the difference $D_c - D_s$ decreases, either T or Δ, correspondingly decrease.

The scales for D_c, D_s, and Δ are arranged in an arbitrary manner; their arrangement on the respective discs is only a matter of convenience, and the arrangement of the T scale after the D_c, D_s, and Δ scales are plotted, must be in close agreement with the latter.

In practice, the procedure consists of the following: the value of T is determined for certain given values of D_c, D_s, and Δ, and, while the discs are in a fixed position, corresponding to the given figures, the first division line for T is marked off; the other divisions of the T scale are marked off according to the angle scale adopted for T, where the above-mentioned directions of increase and decrease of the values for T are taken into account.

In order to determine T according to the values of D_c and D_s, the following procedure should be followed: the division mark for D_c is found on the outer disc; by rotating the inner disc, this division line is matched against the corresponding mark on the inner D_s scale; the dials are fixed by the screw; the matching of the division lines is checked; the corresponding value for a given clearance between the bushing and the journal is found on the outer scale for clearances. The wall thickness of the bushing corresponds to the coinciding or to the nearest division mark on the inner scale.

The preparation of scales for the device does not involve any difficulties.

The costs of producing the device are negligible. The appreciable saving in time necessary for the selection contributes to a more efficient operation of the plant.

The device has been tested and successfully used in operation.

CHECKING SQUARES OF OVER 500 mm BY SIMPLE DEVICES

V.I. Nikolaev

If special equipment is not available, the checking of large-size squares of over 500 mm can be performed by simple devices in the following manner. Three straightedges 1, 2, and 3 (Fig. 1) are placed on a plate the size of which should be somewhat larger than that of the square to be checked. Two of the straightedges, 1 and 2, are placed exactly parallel to each other (this is achieved by gauges mounted on a stand) and fixed on the plate (by means of clamps or other devices).

This arrangement can also be secured by means of two equal length standards.

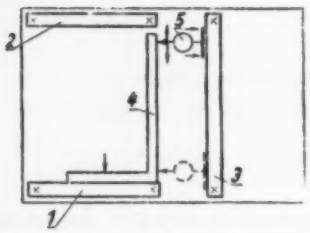


Fig. 1.

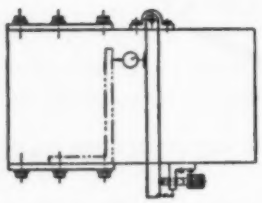


Fig. 2.

After the edges are fixed in an exactly parallel position, the shorter arm of square 4 is placed against one of the edges. As some types of squares have prominent lugs and, sometimes, heads of fastening screws on their shorter arms, care should be taken that the square sides are placed in an approximately parallel position with respect to the plate. Usable or rejected length standards can be used as shims for this purpose.

The reference edge 3 is placed parallel to the longer arm of the square by means of a stand gauge 5 and then fixed in this position.

After all three straightedges are fixed, the square is turned around and its shorter arm is placed against the parallel reference edge 2, and the stand gauge is moved to the other end along straightedge 3.

The gauge needle must be always in contact with the longer arm of the square which is checked. The deviations of the gauge hand correspond to twice the deviation of the square from the right angle on a given length.

An improved variant of this method is shown in Fig. 2.

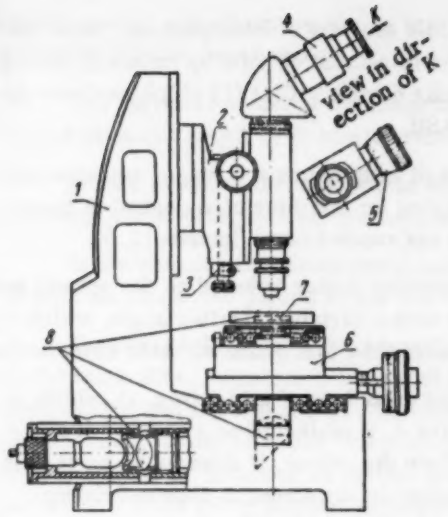
Two edges of the reference plate are shaped to be parallel to each other. Then, two well-ground strips, wide enough to allow a projection of 30-40 mm above the plate surface, are fastened by screws to the plate edges. One end of the third strip (straightedge) must be hinged with a pin so that it can move through a certain angle. The other end of the straightedge must be pressed by an extension spring against a setscrew.

A PRECISION MICROSCOPE FOR THE MEASUREMENT OF SMALL DIMENSIONS

V.E. Kostin

A precision tool microscope for the measurement of small dimensions by the noncontact method has been developed in the Standardization Bureau of the Committee of Standards, Measures, and Measuring Instruments.

A measuring head 2 of a high resolving power is mounted on stand 1 (see figure). A special microfeed 3 is installed in the measuring head for the precision focusing of the object image. A modernized screw-type ocular micrometer 4 (provided with a new grid, a different microscrew, and a scale) is installed in the top part of the head. The reading scale 5 of the microscope is located in the focal plane of the ocular and not in the plane of the stage as in ordinary tool microscopes.



In such a design, the errors due to inaccuracies of pitch and free play of the microscrew pair are reduced as the magnification of the microscope objective increases; correspondingly, the scale divisions of the ocular screw micrometer become smaller. Thus, for instance, for a magnification of 200 x, a division on the scale is equal to 0.004 mm. For convenience in work, the ocular screw micrometer is mounted at an angle of 60° by means of a special prism. A small precision table 6 with a small measuring force (200 g) and an additional filter 7 is mounted on the upper side of the stage.

The table can turn through 360°.

The carriage moves on four balls and is pressed against the fixed rest by constant-force springs.

A special illumination system 8 is built into the microscope stand, permitting very accurate measurements of small dimensions without the appearance of diffraction rings or lines. The stand and the support of the smaller tool microscope model were used in the construction. The microcomponents of the latter do not serve for measurements in this construction, and they serve only for shifting the stage when the measured object is placed in the field of vision.

The measurement of dimensions with the precision measuring microscope is performed by absolute and comparative methods. The first method is used with the ocular micrometer, and in the second, the measurements are performed by comparison with a length standard placed between supports.

The object to be measured is placed in the measuring position under the microscope objective by means of screws provided in the microscope stage. The readings obtained by means of the screw-type ocular micrometer are multiplied by the magnitude of its scale division.

The measurement range of the instrument is from 0.01 to 2 mm.

A uniform illumination of the field of vision is achieved by means of longitudinal and radial displacement of the lamp holder in the illuminator housing. The intensity of illumination, depending on the object to be measured, is controlled by a rheostat built into the transformer. The components of the precision microscope consist of standard optical parts.

APPLICATION OF AN OPTICAL INNER BASE RANGE FINDER IN A FACTORY ARRANGEMENT FOR CHECKING DIMENSIONS OF UP TO 25 m

B.E. Kostich

The required accuracy in manufacturing large machined parts is characterized by tolerances which are, on the average, equal to 0.0001 of the length to be measured. Parts of dimensions exceeding 6 m are difficult to produce with the indicated accuracy due to considerable errors of common measuring instruments, which sometimes exceed the tolerance values.

The usually applied measurement method with additional bases, while satisfactory with respect to accuracy, has a number of drawbacks, including the necessity of additional machining of technological reference bases and the impossibility of checking a part after it has been taken off the lathe or the assembly stand.

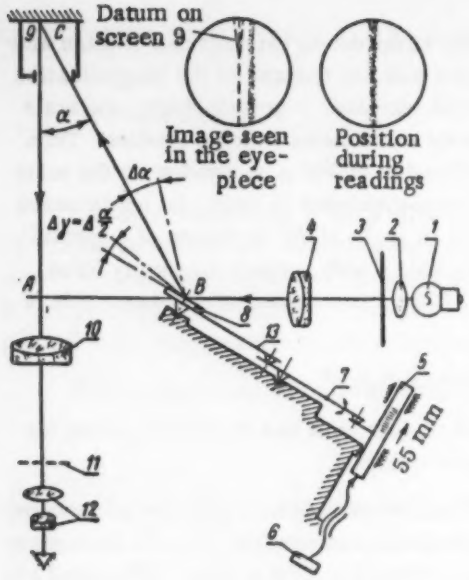


Fig. 1.

The present article provides a description of a new non-contact method for the inspection of parts by means of the universal factory measuring device TsIZM [1] which has been developed by TsNIITMASH.

The application of instruments and length measurement methods used in surveying for the dimension control in heavy machine construction has aroused much interest [2, 3].

The TsIZM measuring device is based on the optical system of a range finder with a variable parallax angle, which secures an accuracy greater than that of the variable base method.

The image of the cross-hair of grid 3 (Fig. 1), which is in the focus of objective 4, is projected on a pivoted mirror 8 and, after reflection from the mirror, is directed to point C on screen 9. The grid image on the screen is observed through telescope 10, 11, and 12. The grid is illuminated by means of lamp 1 and condenser 2. Mirror 8 is rotated by means of a microscrew 6 and intermediate levers 7 and 13. The turning angle of the mirror is determined according to the shift of a glass scale 5 by means of a reading microscope with a helical vernier (parts of the vertical length gauge IZV-1 were used). Readings of an accuracy of 0.1 μ are taken after the image of grid 3 on screen 9 is made to coincide with grid 11 of the telescope.

As a rotation of the mirror through angle γ causes a beam deflection of $\alpha = 2\gamma$, for a rotation radius of mirror 8 equal to 100 mm, the scale 5 moves through a distance of 55 mm, which provides the possibility of measuring objects having a length from 6 to 22 m. In order to eliminate the influence of free play, the lever system is provided with flat springs, and the carriage where scale 5 is mounted moves in a ball-bearing slideway.

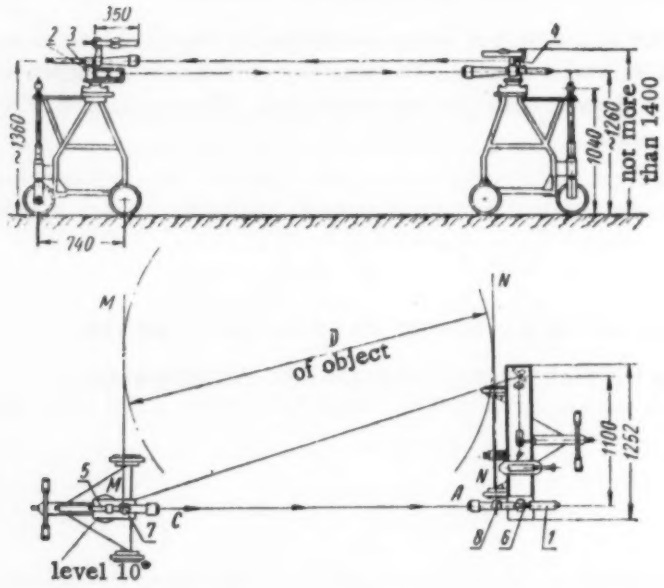


Fig. 2.

For the chosen measurement range and a 1:8 transmission ratio of the lever system, a shift of 1 μ of scale 5 causes the angle α to change by approximately 0.5".

Optical parts, mass-produced by domestic industry were used in the construction of the TsIZM experimental model (Fig. 2). Mobile stands provided with caster wheels permit easy moving of the device in the plant, and

also its setting and alignment during the process of measurement. Before measurements are performed, the wheels should be fixed by brake shoes.

The universal model of the machine is recommended for the inspection of an extensive nomenclature of objects produced singly or in small batches.

In case the instrument is used in mass production, and also where a stand or a machine tool is to be equipped with such a measuring device, the construction can be simplified, and the measurement process made easier.

In the noncontact measurement method (Fig. 2), the measuring instrument and the reflector are mounted on suitable stands and placed at the end faces of the object measured.

The main telescope of the range finder 1 is sighted on a datum of bisector form provided on reflector 2. At the same time, telescope 3 is sighted by another operator on a similar datum 4 which is mounted on the measuring device and is coaxial with telescope 1 in the vertical plane. After telescopes 1 and 3 are focused on the corresponding datum bisectors, the telescope axes will be in the common vertical plane AC. By this, and also by the adjustment by means of an optical prism, the auxiliary telescopes placed at distance measurement nodes 5 and 6 are sighted along parallel lines ($M-M \parallel N-N$). The object size is compared with the length of side AC of the parallax triangle of the range finder by means of adjustable pentahedron prisms 7 and 8.

The displacement of pentahedron prisms 7 and 8 when they are sighted on the object contours (or special marks) is added to the length determined from the parallax triangle according to the readings on scale 5 (see Fig. 1) of the range finder. As a result, the dimension of the object is obtained.

The divisions of scale 5 (see Fig. 1) of the range finder can be determined analytically, however, in order to reduce the measurement errors, it is convenient to calibrate the scale at separate points according to standard measures the length of which is known with sufficient accuracy, for instance, according to Invar wires or tape measures provided in the standard survey equipment BP-3, and for dimensions of up to 10 m, the calibration can be performed by means of BV machines with the subsequent processing of measurement results [4].

In testing the TsIZM experimental model in laboratories and plants, the adjustments were made according to a specially designed and prepared length standard permitting the reproduction of lengths of up to 30 m with errors not exceeding $\delta = 0.00001$ L, which is suitable for the certification of flexible measures. The test results showed that the range finder construction is not sensitive to disturbances such as vibrations in the plant and refraction.

The time required for one measurement is approximately equal to 15 min; in tests, the maximum measurement error was $\Delta_{lim} = 3\sigma = 0.00008$ L.

LITERATURE CITED

[1] B.E. Kostich and L.Ya. Shevchenko, Author's files No. 110813, Dec. 7, 1957.

[2] S.V. Eliseev, A Range Finder for Use in Machine Construction, Bulletin of MVO Colleges, USSR, Surveying and Aerial Photography 1, 1957.

[3] N.P. Sobolev, Optics in Metal-Cutting Machine Tools [in Russian] (Mashgiz, 1958).

[4] A.M. Dlin, Mathematical Statistics in Technology [in Russian] (Moscow, 1958).

MECHANICAL MEASUREMENTS

MEASUREMENTS OF PRESSURES DEFINED BY THE RELATION $P = P_0 + p(t)$ FOR $p(t) \ll P_0$

R.G. Karpov

At the present time, the problem of measuring quickly changing pressures can be solved by means of any of the numerous data transmitters used in measurement techniques (inductive, piezoelectric, induction, capacitive, angle, and other data transmitters).

In all enumerated types of data transmitters, the element sensing the pressure changes is most often a flat or a corrugated membrane which is more or less rigid (depending on the magnitude of the pressure measured). The membrane deflection, determined by the instantaneous value of the pressure measured, is transformed into variations of capacitance, resistance, or charge, which are proportional to the pressure measured. The changes of the indicated quantities are transformed, by means of suitable electric or electronic circuits, into proportional variations of current or voltage which are measured by indicating instruments or recorded by means of oscillographs in the form of $U = kp(t)$ curves.

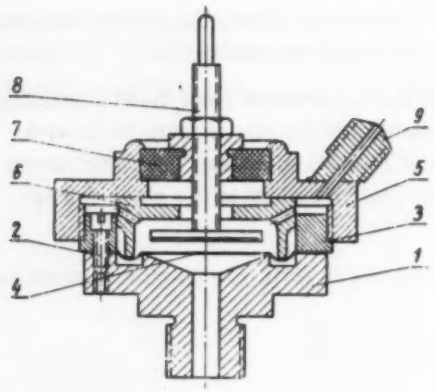


Fig. 1.

By means of these data transmitters, the measurement of variable pressures can be performed with sufficient accuracy in cases where the magnitude of the steady component is commensurable with the pulsation amplitude, however, not a single one of the indicated data transmitters is suitable for the measurement of pulsating pressures where the ratio between the pulsation amplitude and the steady component of the pressure measured is small, i.e., pressures which can be represented by the following expression

$$P = P_0 + p(t) \quad \text{for} \quad p(t) \ll P_0.$$

However, such problems are often encountered, for instance, in motor construction while investigating the influence of pressure pulsation in the tube feeding the fuel to the jet on the quality of atomizing; in investigating the influence of pressure pulsation past the supercharger in an aircraft motor on the quality of mixture; in measuring the pressure pulsation in gas turbine motors, etc.

In these cases, the application of the usual methods of pressure measurements involves certain difficulties. In the first place, the data transmitter and the measuring mechanism must be designed for the maximum intensity of the expected pressure $P_{max} = P_0 + p(t)_{max}$, i.e., the data transmitter must be provided with a sufficiently rigid membrane able to withstand maximum pressures without residual deformations. It is perfectly obvious that such a membrane will not be able to react to small pressure changes where $p(t) \ll P_0$. It is impossible to use a weaker membrane able to react to small pressure variations which are determined by the amplitude of pulsations because of the danger of additional measurement errors caused by residual deformations of the membrane or, even, by its failure due to the large steady component P_0. On the other hand, in direct measurements of pressures defined by $P = P_0 + p(t)$, the scale of the measuring instrument is utilized in a very inefficient manner. In this case, the whole scale must be designed for the magnitude P_{max}, and the scale section corresponding to the small variable component of the pressure investigated, which is of interest to the experimenter, will be very small, and will augment the reading errors.

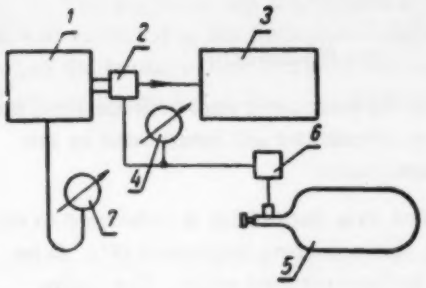


Fig. 2. 1) The device under investigation (receiver, piping, etc.); 2) data transmitter; 3) metering arrangement; 4) pressure gauge for counterpressure P_C; 5) compressed air container; 6) pressure regulator; 7) gauge for the steady component P_0.

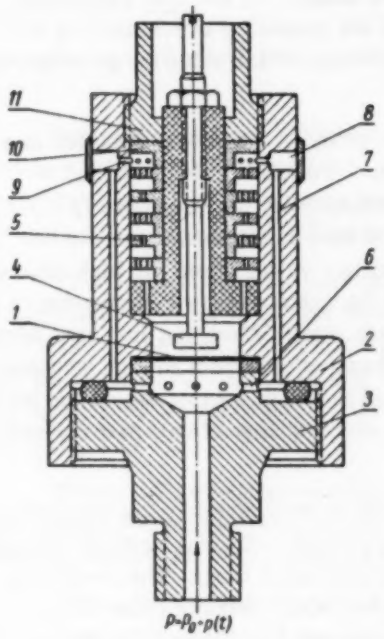


Fig. 3.

A capacitance data transmitter with steady counterpressure and a capacitance data transmitter with a pressure choke were used in the described device for the measurement of pressures where the ratio between the pulsation amplitude and the steady component was small.

The capacitance data transmitter was constant counterpressure (Fig. 1) consists of a steel housing 1 with a fitting for the connection to the machine under investigation. A thin membrane 4, acting as the mobile plate of the data transmitter capacitor, is fastened to the housing by means of screws 2 and washer 3. The membrane is kept uniformly taut by means of a tightening screw 5 screwed on washer 3, and a profiled insert 7. The fixed plate of the data transmitter capacitor is insulated from the housing by means of a polystyrene collar 8 fitted into a special recess in nut 5.

The initial capacitance of the data transmitter can be regulated within a certain range by means of screwing in or screwing out rod 9 which has a thread pitch t = 0.2 mm.

A steady counterpressure P_C is admitted to the membrane from the side of the fixed plate through connecting piece 9 and the opening in part 6.

The data transmitter is connected to the device according to the layout given in Fig. 2.

Thus, one side of the membrane is acted upon by the pressure $P = P_0 + p(t)$ under investigation, and the other side, by the artificially created air pressure $P_C = P_0$ from container 5. Then, the deflection of the membrane will be caused only by the variable component $p(t) \ll P_0$ of the pressure to be investigated, and, consequently, the membrane can be sufficiently thin.

This data transmitter yielded good results in cases where the steady pressure component P_0 did not change. However, for gradual changes in P_0, the experimenter must continuously control the magnitude of P_0, adjusting the counterpressure in correspondence with the chosen value of P_0.

A data transmitter with a pressure choke (Fig. 3) appeared to be more suitable for the measurement of pressure defined by $P = P_0 + p(t)$ where the constant component varied. A thin membrane 1 made of stainless steel was used as the mobile plate in this data transmitter (a cold-rolled brass foil can be also used). The membrane thickness is selected with respect to the expected pulsation amplitude. The membrane is fixed in a special recess in frame 2 by part 3 which is provided with a fitting for the connection to the device under investigation. The distance between the membrane and the fixed plate 4 can be regulated in order to provide a given initial capacitance C_0 of the data transmitter. After its position has been regulated, the fixed plate is secured by a nut. The cylindrical space inside the housing contains a choking device consisting of a set of six metallic discs 5 with ten openings 0.6 mm in diameter, which are uniformly distributed along the end faces of the discs.

The pressure $P = P_0 + p(t)$ acts on the membrane from the side of the device which is being tested. This pressure is transmitted through openings 6 and channels 7 into the ring-shaped recess 8, and from there, to the choking device through openings 9.

Such an arrangement, which is a high-frequency filter, transmits only the slowly changing steady component P_0 and smothers the pressure pulsations. Consequently, the membrane which is acted upon on its one side by pressure $P = P_0 + p(t)$, and on its other side by pressure P_0, will be deflected only under the action of the variable component of the pressure in question

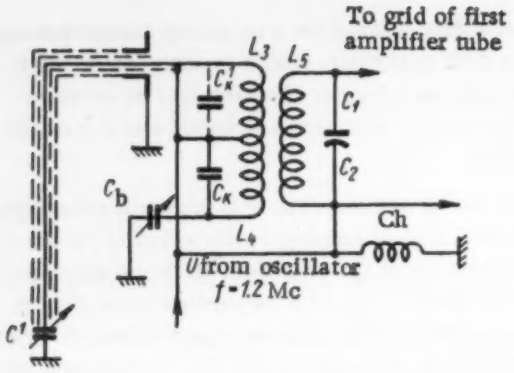


Fig. 4.

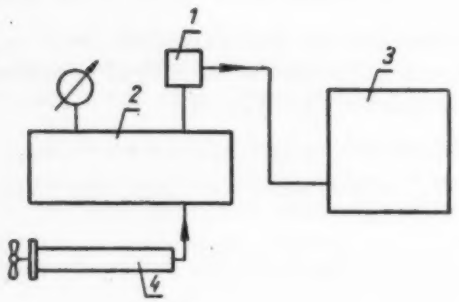


Fig. 5.

$$\Delta p = P - P_0 = p(t).$$

The rigidity of the membrane and, consequently, the sensitivity of the data transmitter are determined by the expected pulsation amplitude.

The capacitance data transmitter is connected to one arm of the bridge in the measuring instrument (Fig. 4) by means of a coaxial double-screened cable. The bridge arms are formed by the data transmitter capacitor C_x, by the capacitor C_b used for the initial balancing of the bridge when the data transmitters are interchanged, and by two inductance coils L_3 and L_4. The distributed capacitance C'_c of the cable is connected in parallel to L_3 between the conductor and the inner screen (the outer screen is grounded). The capacitor C_c, which balances the capacitance C'_c of the cable, is connected in parallel to L_4.

Such a scheme of connecting the data transmitter and the cable provides the possibility of eliminating the influence of self-capacitance of the cable on the sensitivity of the circuit.

A 12-m-long RK-49 cable, which was sheathed in a securely grounded screen, was used in the described arrangement. A high-frequency Hartley oscillator (f = 1.2 Mc) with a 6P6 tube was used as the feed source for the bridge. The high-frequency voltage from the high-frequency oscillator was supplied through a stepdown transformer (n = = 10:1) to the feed diagonal of the bridge and to the amplifier and the detector chassis which was insulated from ground with respect to high frequency. Such an insulation of the amplifier chassis with respect to high frequency (with respect to direct current, it was grounded by means of choke Ch) reduced to a considerable extent the leakage of high-frequency energy from the measuring diagonal of the bridge into the amplifier circuit past the control channel.

The voltage from the measuring bridge diagonal, the magnitude of which is determined by the instantaneous value of the pressure p(t) to be measured, is transmitted through the L_5-C_1 circuit, which is tuned to 1.2 Mc, to the grid of the first amplifier tube of a two-stage high-frequency amplifier with 6Zh4 tubes. The amplified voltage, the amplitude of which changes in proportion to the pressure p(t), is fed to the detector (tube 6Kh6), where the voltage of the envelope of high-frequency oscillations U = kp(t) is separated and then amplified by the low-frequency amplifier of the indicating part of the device.

The frames of the L_1-L_2 and $L_3-L_4-L_5$ transformers are made of polystyrene (d = 8 mm) with windings of PÉShO wire (d = 0.2 mm); $L_1 = L_2 = 200$ windings and $L_2 = L_3 = L_4 = 20$ windings. The inductance coils L_3 and L_4 are made in two sections placed side-by-side, and the single-section inductance coil L_5 is placed symmetrically between L_4 and L_3. Both transformers are placed inside aluminum screens. Thus, AM high-frequency oscillations with an envelope changing in correspondence to changes in the pressure p(t) are fed to the grid of the high-frequency amplifier. After amplification, this voltage is detected.

The output voltage from the detector can be measured by a tube voltmeter graduated in effective or peak values. However, more complete information on the pressure under investigation (amplitude of pulsation, frequency, and shape) can be obtained only by means of plotting the U = kp(t) curve by means of an oscillograph.

A slightly modified ÉO-7 cathode-series oscillograph provided with a photographic adapter was used for plotting the U = kp(t) curve. The necessary changes in the ÉO-7 circuit pertained mainly to the scanning unit.

In the circuit breaks of conductors connecting R_{40} to the anode of the thyratron of the scanning oscillator and to one of the charging capacitors, a toggle switch is used for shorting these breaks for periodic scanning (for instance, for the visual observation of the process under investigation) and for breaking the circuit at these points when single sweeps are used in photographing the peak of the p(t) curve.

The toggle switch is extended to the front panel of the oscillograph. A normally open button switch, which is also extended to the front panel and serves for triggering the single sweep, is connected in parallel to the break. When the button switch is closed, the capacitor selected by the "Frequency Range" switch is charged through a large resistance R_{40}, and the voltage on the capacitor increases according to the law

$$U_c = U_0 \left(1 - e^{-\frac{t}{RC}}\right),$$

causing a single sweep of the beam along the time axis, since the voltage U_C is fed to the input of the horizontal amplifier.

The use of such scanning in photographing is dictated by its following three advantages.

In the first place, the curve in question will be recorded by a single sweep of the beam and the photograph will not be blurred by "additional" lines which appear in photographing by means of continuous scanning due to repeated sweeping of the electron beam over the screen.

In the second place, by reducing the sweeping rate, it is possible to produce the so-called railing, i.e., to fix the pulsation amplitude for a large number of periods, which will permit an evaluation of the stability or of the character of pulsation amplitude variations and, thus, the obtaining of additional information on the process under investigation.

In the third place, such scanning is characterized by extreme simplicity with an acceptable degree of linearity.

For the vertical amplification channel, the modification consisted of disconnecting only the first cascades. The signal from the detector load was fed to the grid of the second cathode follower, which permitted the measurement of fast and slow pressure changes as well as steady pressure. The indicated modification was prompted by a desire to simplify the calibration of the measuring device with respect to pressure.

The calibration of the measuring device with respect to pressure was performed by means of an auxiliary arrangement (Fig. 5). The data transmitter 1 was screwed into a special socket in the metal receiver 2 and was connected to the measuring circuit 3. By means of pump 4, a pressure, measured by means of pressure gauge 5 and equal to $P_1, P_2, P_3, \ldots P_i$ mm wc, was created in the receiver. Afterward, by using single sweeps, successive photographs of the beam trace were taken (on the same plate), which corresponded to the given steady pressures $P_1, P_2, P_3, \ldots P_i$.

Before the measuring circuit was calibrated with respect to pressure, instead of part 10 (see Fig. 3), a compact rubber washer was placed in the data transmitter and fastened by nut 11 in order to shut off the choking device, as, otherwise, equal pressures would be acting on both sides of the membrane.

Afterward, the plotting of calibration graphs and the processing of oscillograms with respect to the pressure axis were performed in the usual manner.

The calibration with respect to the time axis was performed by means of the ZG-10 sound generator by feeding voltage of a certain frequency to the tube modulator. The regions of heightened intensity, spaced at a distance proportional to $T_{inv} = 1/f_{inv}$, are marked off on the oscillogram.

When oscillograms of complex pulsations are produced, the calibration with respect to the time axis is more conveniently performed by photographing a sinusoid of standard frequency on the same plate. In this case, instead of the voltage to be analyzed, the voltage from a standard oscillator is fed to the vertical input of the oscillograph.

The described measuring device was applied in the investigation of the T-130 automatic acetylene lighthouse lamp where the average pressure in the regulation chamber gradually changed within 600-700 mm wc. The instantaneous magnitude of pressure was changing at a considerable frequency (from 5-8 to 15-18 cps), which was determined by the operating conditions of the lamp. The amplitude of pressure pulsations rarely exceeded 10-12 mm wc. Thus, the pressure measured corresponded to the expression

Initially, a data transmitter of the first type (with steady counterpressure) with a membrane d = 20 mm in diameter made of thin (δ = 0.02 mm) cold-rolled brass foil was used in measurements. The diameter of the fixed data transmitter plate, which was made of brass, was equal to 10 mm in all specimens of this type of data transmitters. The initial capacitance C_0 of the data transmitter was equal to 12.5 $\mu\mu$f.

The $\Delta C = f(p)$ curve was plotted for each newly manufactured data transmitter with the aim of determining the operating range of the pressures measured within the linear portion of the curve.

For the majority of data transmitters, the nonlinearity of the characteristic is kept within allowable limits when the capacitance of the data transmitters changes by 12-15% of the initial value.

The $\Delta C = f(p)$ characteristic was plotted by means of an auxiliary unit which was an audio node oscillator (frequency of master oscillators $f = 1 \cdot 10^6$ cps).

A variable capacitor with a vernier mechanism (delay 1:4) and a scale graduated in fractions of μf was connected to the oscillating circuit of the first master oscillator.

The variable capacitor of the data transmitter was connected in parallel to the trimmer in the oscillating circuit of the second master oscillator. For P = 0 and the initial value of data transmitter capacitance, the oscillators were tuned for equal frequencies by varying the trimmer capacitance with respect to zero nodes. For fixed pressure intensities equal to $P_1, P_2, \ldots P_i$ at the data transmitter, its capacitance changed by $\Delta C_1, \Delta C_2, \ldots \Delta C_i$, and the frequency of the second oscillator changed accordingly.

The resultant detuning was compensated for by adjusting the capacitance of a standard capacitor, where the magnitudes $\Delta C_1, \Delta C_2, \ldots \Delta C_i$, corresponding to the applied pressures $P_1, P_2, \ldots P_i$, were determined on the capacitor scale.

The $\Delta C = f(p)$ curve, according to which the linear portion of the obtained curve and the data transmitter sensitivity $S = d\Delta C/dP$ were determined, was plotted according to the values obtained for ΔC_i and P_i. The best value of the data transmitter sensitivity for an acceptable natural frequency (f_0 = 218 cps), was equal to

$$S = \frac{d\Delta C}{dP} = \frac{0.017 \ \mu\mu f}{10 \ \text{mm} \cdot \text{wc}}.$$

By reducing the membrane tension by means of a profiled insert 6 (see Fig. 1), it was possible to increase the sensitivity to a considerable extent. However, this was accompanied by a sharp decrease in the natural oscillation frequency f_0, which is not always permissible.

The data transmitter with a pressure choke had a smaller membrane (d = 15 mm), which provided the possibility of increasing the natural oscillation frequency to 330-340 cps with a negligible deterioration of sensitivity.

The natural frequency of data transmitters was determined experimentally by means of a standard audio oscillator. For this purpose, the data transmitter, which was connected to a measuring circuit with a cathode oscillograph at the output, was placed in the audio field of a dynamic loudspeaker (the dynamic loudspeaker was excited by a standard audio oscillator through a power amplifier of W = 12w) in such a way that the membrane plane was perpendicular to the direction of propagation of sound waves.

A vertical line of a length proportional to the amplitude of membrane oscillations appeared on the oscillograph screen when the amplification along the X–X axis was switched off.

The natural frequency of the data transmitter was determined according to readings taken on the scale of the standard oscillator for the maximum amplitude of membrane oscillations.

The high frequency of the data transmitter natural oscillations in comparison with the frequency of pulsations to be recorded permitted only the static calibration of the measuring device, which was performed according to the method described.

The given values for the data transmitter sensitivity and the frequency of its natural oscillations can change when the temperature of the surrounding medium varies, and, therefore, when conducting important measurements, it is necessary to perform the calibration of the measuring circuit for several temperature values corresponding to the expected conditions encountered in practice.

DETERMINATION OF STATIC CHARACTERISTICS OF A FORCE-COMPENSATION SYSTEM CONTAINING AN ELASTIC TUBE

M.Kh. Lantsman

The application of elastic tubes as hinge and distribution links in compensation devices with force compensation permits an almost complete elimination of the influence of large static forces in sensitive element chambers on the measurement process.

An elastic tube has great rigidity and determines to a great extent the choice of the basic parameters of a compensation system.

Such a device (Fig. 1) consists of the sensitive element 1 which develops a force P_P proportional to the quantity measured, of a transmission lever 2 placed inside an elastic tube 3 and rigidly fastened at its right-hand side end, of a feedback system consisting of a feedback lever 4 connected to transmission lever 2, a control unit 6, an amplifier 7, and a terminal unit 5. A force P_O, proportional to the output pulse of the system, arises in element 5.

The feedback can be effected by electrical, pneumatic, or hydraulic couplings.

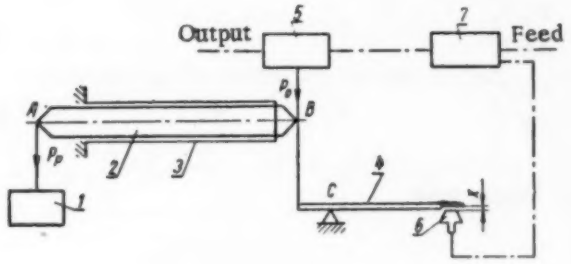


Fig. 1.

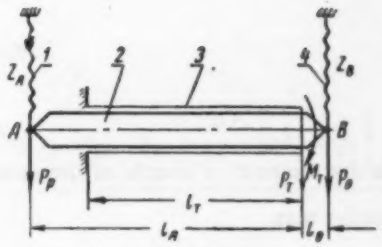


Fig. 2.

In the static state, the force P_P arising in the sensitive element is balanced by force P_O, generated by the terminal element where the necessary magnitude of the output pulse is maintained automatically. When the quantity to be measured changes, the system is thrown out of balance and the position of the transmission lever and of the feedback lever changes, which causes a change in clearance $\underline{x}$ in the control unit. Due to the change in $\underline{x}$, the output pulse also changes, and, correspondingly, so does the force P_O in the terminal unit, until a new equilibrium state is reached.

The necessary value for P_O is determined by the static equilibrium of forces in the system, and, therefore, the changes in the force P_O and the output pulse must be proportional to changes in force P_P, i.e., to the quantity which is measured.

For the sake of simplicity, let us assume that P_P and P_O are the values of the quantity to be measured and of the output pulse, respectively.

As a rule, the change in the force P_O is related to the variation of clearance $\underline{x}$ by a nonlinear dependence. This nonlinearity is conditioned by the general character of the dependence of P_P on $\underline{x}$, and also by the existence of a certain insensitivity region of the control unit. The variation of clearance $\underline{x}$, which corresponds to the deviation from linearity of the output pulse, will be called the insensitivity of the control unit and denoted by $\delta(x)$.

The analysis will be much simpler if we use an equivalent arrangement (Fig. 2). It has a transmission lever 2 placed inside an elastic tube 3. The acting force P_P is applied to the end A of the lever and the feedback coupling force P_O, which is proportional to the output pulse, is applied to the end B. The influence of positional forces, which are due to the rigidity of links in an actual arrangement, was taken into count by introducing into the equivalent arrangement springs 1 and 4, with respective rigidities Z_A and Z_B equal to the given rigidities of elements connected to the transmission lever at points A and B.

If we assume that, in the initial position, the forces acting on lever 2 and the displacements of points A and B are equal to zero, the new state can be described by the following equations:

$$\begin{gathered} P_P - Z_A V_A + P_O - Z_B V_B = P_T, \\ (P_O - Z_B V_B)\, l_B - (P_P - Z_A V_A)\, l_A = M_T, \\ V_B = V_T + l_B \varphi_T, \\ V_A = V_T - l_A \varphi_T + k_A (P_P - Z_A V_A), \end{gathered} \tag{1}$$

where P_T and M_T are the force and the moment applied to the end of the elastic tube (at the point T); V_T and φ_T are the displacement and the turning angle of the end cross section of the elastic tube (at the point T); V_B is the displacement of the lever end (at the point B); V_A is the displacement of the lever end (at the point A); k_A is a coefficient characterizing the rigidity of the lever arm l_A (for a cylindrical rod, $k_A = l_A^3/3EI_A$. Here E is the modulus of elasticity of the material in the rod, and I_A is the moment of inertia of the cross section of the rod).

Due to the small length of the lever arm l_B, its deformation is not considered.

The first two equations for the system represent the equilibrium conditions for the lever, and the remaining equations establish the relations between the displacements of points A and B of the lever.

The displacement V_T and the rotation angle φ_T of the end cross section of the elastic tube at the point T are proportional to the force P_T and to the moment M_T:

$$V_T = \frac{M_T l_T'}{2 E I_T} + \frac{P_T l_T'}{3 E I_T}, \tag{2}$$

$$\varphi_T = \frac{M_T l_T}{E I_T} + \frac{P_T l_T'}{2 E I_T}, \tag{3}$$

where I_T is the moment of inertia of the cross section of the elastic tube.

Assuming that

$$P_{PP} = P_P - Z_A V_A, \tag{4}$$

$$P_{OO} = P_O - Z_B V_B, \tag{5}$$

we obtain:

$$\begin{aligned} V_T &= \frac{M_T l_T'}{2 E I_T} + \frac{P_T l_T'}{3 E I_T} = \frac{P_{OO} l_B - P_{PP} l_A}{2 E I_T} l_T' + \frac{P_{OO} + P_{PP}}{3 E I_T} l_T' = \\ &= \frac{l_T'}{3 E I_T} \left[P_{OO}(1.5 l_B + l_T) - P_{PP}(1.5 l_A - l_T) \right], \end{aligned} \tag{6}$$

$$\varphi_T = \frac{M_T l_T}{E I_T} + \frac{P_T l_T'}{2 E I_T} = \frac{P_{OO} l_B - P_{PP} l_A}{E I_T} l_T + \frac{P_{OO} + P_{PP}}{2 E I_T} l_T^2 = \frac{l_T'}{3 E I_T} \left[P_{OO} \frac{1.5}{l_T}(2 l_B + l_T) - P_{PP} \frac{1.5}{l_T}(2 l_A - l_T) \right]. \tag{7}$$

whence:

$$\begin{aligned} V_B = V_T + \varphi_T l_B &= \frac{l_T'}{3 E I_T} \left[P_{OO}(1.5 l_B + l_T) - P_{PP}(1.5 l_A - l_T) \right] + \frac{l_T' l_B}{3 E I_T} \left[P_{OO} \frac{1.5}{l_T}(2 l_B + l_T) - P_{PP} \frac{1.5}{l_T}(2 l_A - l_T) \right] = \\ &= \frac{l_T'}{3 E I_T} \left\{ P_{OO} \left[\frac{1.5 l_B}{l_T}(2 l_B + l_T) + 1.5 l_B + l_T \right] - P_{PP} \left[1.5 \frac{l_B}{l_T}(2 l_A - l_T) + 1.5 l_A - l_T \right] \right\}. \end{aligned}$$

Further, assuming that:

$$L_A = 1.5 \frac{l_B}{l_T}(2 l_A - l_T) + 1.5 l_A - l_T, \tag{8}$$

$$L_B = 1.5\frac{l_B}{l_T}(2l_B + l_T) + 1.5\,l_B + l_T, \tag{9}$$

$$N_T = \frac{3\,E\,I_T}{l_T^3}, \tag{10}$$

we obtain

$$P_{OO}\,L_B - P_{PP}\,L_A - N_T\,V_B = 0$$

or

$$(P_O - Z_B\,V_B)\,L_B - (P_P - Z_A\,V_A)\,L_A - N_T\,V_B = 0 \tag{11}$$

The transmission ratio $k_c = dP_O/dP_P$ of the system can be found by differentiating Eq. (11) with respect to P_P:

$$\left(k_c - Z_B\frac{d\,V_B}{d\,P_P}\right)L_B - \left(1 - Z_A\frac{d\,V_A}{d\,P_P}\right)L_A - N_T\frac{d\,V_P}{d\,P_P} = 0.$$

The displacement V_A (1) will be equal to:

$$V_A = \frac{V_T - l_A\,\varphi_T + k_A P_P}{1 + Z_A\,k_A}.$$

Substituting the values for V_T and φ_T from (6) and (7), we find:

$$V_A = \frac{\frac{l_T^3}{3\,E\,I_T}\left[P_{OO}(1.5\,l_B + l_T) - P_{PP}(1.5\,l_A - l_T)\right] - \frac{l_T^3}{3\,E\,I_T}\left[P_{OO}\frac{1.5\,l_A}{l_T}(2\,l_B + l_T) - P_{PP}\frac{1.5\,l_A}{l_T}(2\,l_A - l_T)\right] + k_A P_P}{1 + Z_A\,k_A}$$

$$= \frac{\frac{1}{N_T}\left\{P_{PP}\left[\frac{1.5\,l_A}{l_T}(2l_A - l_T) - 1.5\,l_A + l_T\right] - P_{OO}\left[\frac{1.5\,l_A}{l_T}(2\,l_B + l_T) - 1.5\,l_B - l_T\right]\right\} + k_A P_P}{1 + Z_A\,k_A}. \tag{12}$$

Assuming that:

$$C_A = 1.5\frac{l_A}{l_T}(2\,l_A - l_T) - 1.5\,l_A + l_T, \tag{13}$$

$$C_B = 1.5\frac{l_A}{l_T}(2\,l_B + l_T) - 1.5\,l_B - l_T, \tag{14}$$

we obtain

$$V_A = \frac{\frac{1}{N_T}(P_{PP}\,C_A - P_{OO}\,C_B) + k_A P_P}{1 + Z_A\,k_A},$$

or, according to relations (4) and (5):

$$V_A = \frac{\frac{1}{N_T}\left[(P_P - Z_A V_A)\,C_A - (P_O - Z_B V_B)\;C_B\right] + k_A P_P}{1 + Z_A\,k_A}.$$

By simple transformations, we find:

$$V_A=\frac{\frac{1}{N_T}(P_P C_A-P_O C_B)+k_A P_P+Z_B\frac{C_B}{N_T}}{1+k_A Z_A+Z_A\frac{C_A}{N_T}}, \tag{15}$$

whence:

$$\frac{d V_A}{d P_P}=\frac{\frac{1}{N_T}(C_A-k_c C_B)+k_A+Z_B\frac{C_B}{N_T}\cdot\frac{d V_B}{d P_P}}{1+k_A Z_A+Z_A\frac{C_A}{N_T}}.$$

Denoting:

$$k_n=-\frac{d V_B}{d P_O}, \tag{16}$$

we obtain:

$$\frac{d V_A}{d P_P}=\frac{d V_B}{d P_O}\cdot\frac{d P_O}{d P_P}=-k_n k_c \tag{17}$$

and

$$\frac{d V_A}{d P_P}=\frac{\frac{1}{N_T}(C_A-k_c C_B)+k_A-Z_B\frac{C_B}{N_T}k_n k_c}{1+k_A Z_A+Z_A\frac{C_A}{N_T}}.$$

Substituting the obtained relations in (12), we find:

$$(k_c+Z_B k_n k_c)\,L_B-\left[1-Z_A\frac{\frac{1}{N_T}(C_A-k_c C_B)+k_A-Z_B\frac{C_B}{N_T}k_n k_c}{1+k_A Z_A+Z_A\frac{C_A}{N_T}}\right]L_A+N_T k_n k_c=0,$$

whence:

$$k_c=-\frac{L_A}{L_B\left[r_{AT}+\left(Z_B r_{AT}+\frac{N_T}{L_B}r_A+Z_A\frac{C_A}{N_T}\right)k_n\right]}, \tag{18}$$

where

$$r_A=1+k_A Z_A, \tag{19}$$

$$r_{AT}=1+k_A Z_A+\frac{Z_A}{N_T L_B}(C_A L_B-C_B L_A). \tag{20}$$

As k_n is a small quantity, we can assume with sufficient accuracy that

$$k_c\simeq\frac{L_A}{L_B r_{AT}}. \tag{21}$$

The error δP_P due to the insensitivity of the control element is determined by differentiating (11) under the assumption that the feedback coupling force P_θ remains constant:

$$-Z_B L_B\delta V_B-(\delta P_P-Z_A\delta V_A)L_A-N_T\delta V_B=0.$$

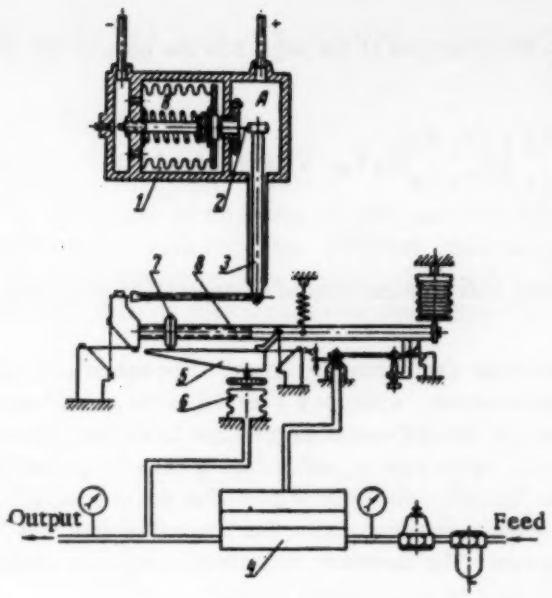


Fig. 3.

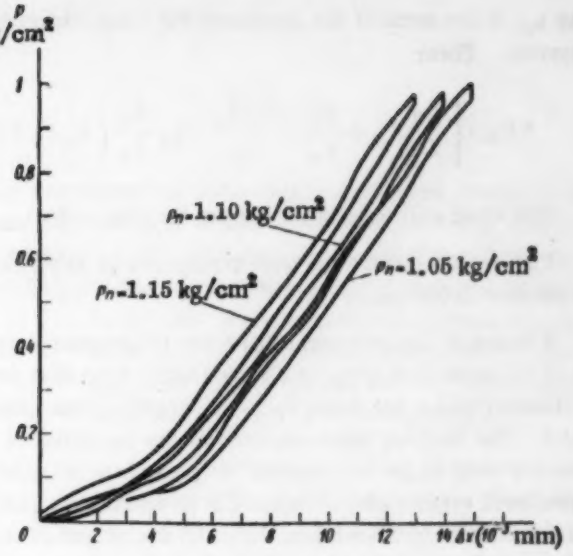


Fig. 4.

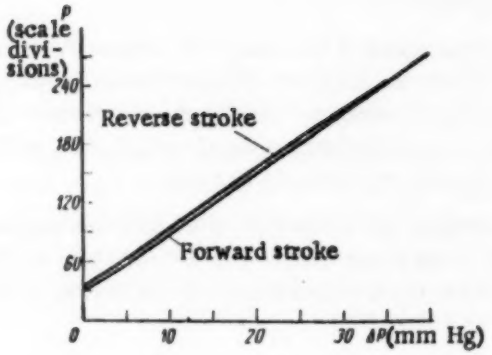


Fig. 5.

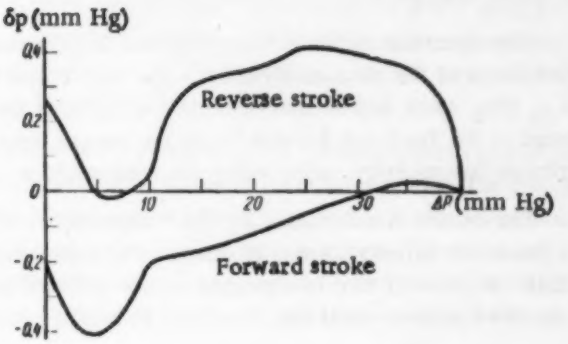


Fig. 6.

According to (15):

$$\delta V_A = \frac{\frac{1}{N_T} C_A \delta P_p + k_A \delta P_p + Z_B \frac{C_B}{N_T} \delta V_b}{1 + k_A Z_A + \frac{Z_A C_A}{N_T}},$$

whence:

$$-Z_B L_B \delta V_B - \delta P_p L_A + Z_A \frac{\frac{1}{N_T} C_A \delta P_p + Z_B \frac{C_B}{N_T} \delta V_B}{1 + k_A Z_A + \frac{Z_A C_A}{N_T}} L_A - N_T \delta V_B = 0.$$

Considering that the displacement V_B is linearly related to the displacement x,

$$\delta V_B = -k_{3B} \delta (x), \tag{22}$$

where k_{3B} is the ratio of the displacement transmission from the lever end at the point B to the control unit of the system. Then:

$$\delta P_P = \left[\frac{L_B}{L_A} Z_B + \frac{N_T}{L_A} + \frac{C_A Z_A}{L_A} + k_A \frac{L_B}{L_A} \left(Z_A Z_B + Z_A \frac{N_T}{L_B} \right) + \frac{Z_A Z_B}{N_T L_B} (C_A L_B - C_B L_A) \right] k_{3B} \delta(x). \quad (23)$$

The error will be at a maximum for $\delta(x) = \delta(x)_{max}$.

The obtained relations were confirmed by experimenting with constructions of compensating pneumatic pressure-drop detectors.

A batch of experimental SDPP-40-16 pressure-drop detectors was thoroughly tested. The operational principle of these devices (Fig. 3) differed little from that described above. A bellows 1 served as the elastic sensitive element where the force P_P to be measured was generated by the difference in pressures in working chambers A and B. The bellows was connected to the transmission lever 3 by an elastic pull rod 2. A pneumatic feedback system was used in the instrument. A pneumatic relay of the "nozzle-gate" type was used as the control unit. The feedback system also comprised a pneumatic amplifier 4 and a terminal unit. The latter consisted of a lever 5 and a feedback bellows 6 connected to the output of the device. The necessary transmission ratio was obtained by adjusting the position of the knife support 7 which was mounted on the feedback lever 8.

The device is supplied with dry purified compressed air from the main supply; the pressure is reduced to 1.1 ± 0.05 kg/cm^2. The output air pressure, corresponding to a variation of the pressure drop to be measured from 0 to 100%, changes from 0.1 to 0.9 kg/cm^2 (or from 0.2 to 1.0 kg/cm^2).

The operation of the feedback system is governed by the dependence of the change in pressure P_O on the variation Δx of the clearance between the nozzle and the gate. From the graph for different values of feed pressure p_n (Fig. 4), it can be seen that the variation of the clearance x, necessary for varying the compressed air pressure in the feedback bellows (or at the system output) from 0.1 to 0.9 kg/cm^2, is equal to 0.01 mm, while the maximum insensitivity, considering the feed pressure variation, is equal to $\delta(x) = 0.0015$ mm.

The device is calculated for the measurement of pressure drops in the range from 0-40 to 0-250 mm wc for a feedback bellows 15 mm in diameter and for pressure drops in the range from 0-100 to 0-400 mm wc for a feedback bellows 21 mm in diameter. As was shown by calculations, the maximum error of the device, considering the feed pressure variation, must not exceed ± 1 mm wc.

The tests were performed on a special stand. The pressure drop was established by means of a micromanometer. The output pressure and the feed pressure were controlled by means of standard pressure gauges of the class 0.35.

The tests confirmed the possibility of adjusting the device in the given intervals, as well as the expected magnitude of measurement errors. Figure 5 shows the plotted characteristic of a device adjusted for the measurement range of 0-40 mm wc when the feed pressure was kept constant. Figure 6 shows the distribution of errors for the given measurement range. The additional error due to the feed pressure variation was equal to 0.6 mm wc. The tests also showed that the static pressure did not appreciably influence the measurement process: the variation in instrument readings, for a change in static pressure equal to 1 kg/cm^2, was equal to 0.07 mm wc.

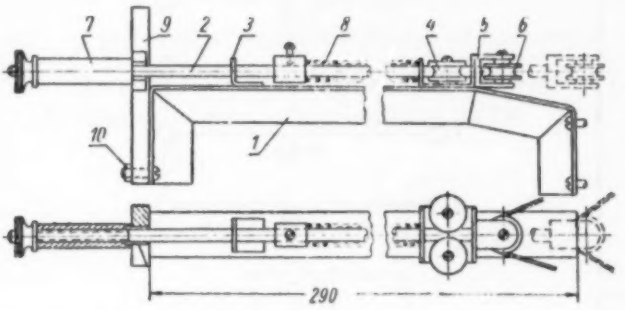
It was established by theoretical and experimental investigations that an elastic tube used as the linkage element can secure with sufficient accuracy the steadiness of the transmission ratio of the system.

The choice of the optimum dimensions of the elastic tube is determined by the minimum of relation (23). An increase in displacements V_A and V_B, which can be a source of additional errors, should also be taken into account if a less rigid elastic tube is used.

AN ADAPTER FOR MECHANICAL PRESSURE INDICATORS

Yu.N. Gogin

At the present time, the simplest and most reliable instrument for the indication of piston engines is the mechanical pressure indicator. However, in investigations performed by means of this instrument, it is necessary to stop the machine in order to change the card on the indicator drum. The stopping and starting of the machines when investigation is carried out for many different operating conditions complicates the procedure, especially in the case where certain given operating conditions must be established or when large machines are being tested, the motors of which must not be repeatedly started in quick succession.



In testing reciprocating compressors, the above-mentioned deficiency of mechanical indicators can be eliminated by using an adapter (see figure) designed by the author. A steel rod 2,5 mm in diameter,can move in guides 3 and 4 along bracket 1 made of 20 x 20 angle iron which was bent to shape. A fork 5 with a pulley 6 is fastened at one end of the rod, and a sleeve 7 with a fastening nut is fixed at the other end. When the mechanism is idle, a spring 8 keeps the rod in the extreme left-hand position where it can be fixed by lock 9 consisting of a lever with an arc-shaped recess which is provided for the passage of the rod.

The adapter is fastened to the bracket of the stroke reductor or to the machine under investigation in such a manner that the pulley 6 is placed at the height of the wire from the indicator drum and at a certain distance from it. The adjustment of an indicator provided with an adapter ss done when the piston is in the lower dead-center position. The wire from the indicator drum is wound around pulley 6, forming a loop. The wire is fastened to the stroke reducing mechanism in such a way that when the indicator drum turns until stopped by the stopper, the fork 5 is moved through a distance of 4-5 mm from its extreme left-hand position when lock 9 is open.

The data are taken when lock 9 is closed, and the indicator operates as usual. In order to stop the indicator drum, the lever 9 is rotated about axle 10. Then, sleeve 7 and rod 2 are freed. The tension in the wire when the piston moves out of the dead-center position, which earlier caused the rotation of the indicator drum, will now bring about a change in the length of the loop and the rod will move to the extreme right-hand position shown by dotted lines in the figure (spring 8) is weaker than the spring of the indicator drum). During the reverse stroke of the piston, spring 8 pushes the rod back and increases the length of the loop. Meanwhile, the drum remains immobile, which facilitates a trouble-free replacement of the indicator card.

In order to put the indicator in operation, lever 9 is slowly advanced to sleeve 7, and, at the moment when the rod reaches the extreme left-hand position, the sleeve is locked. In order to make this operation easier and to prevent the fork from touching the guide 4, a wedge-shaped bevel is provided on the rod.

When the adapter was tried out in tests performed on a compressor the shaft of which was turning at 400 rpm, it was established that the device made the testing easier without causing any distortions in the diagram and that its operation was completely reliable.

A REVOLUTION COUNTER

I.P. Lishchinskii

The described instrument, which has been developed in SKB for feed pumps, provides a highly accurate revolution count for pumps used in test stands.

The instrument is reliable for the direct revolution count for any machine the speed of which does not exceed 6000 rpm. For a greater number of revolutions, it is necessary to use a reductor. The instrument is also suitable for checking tachometers and revolution counters.

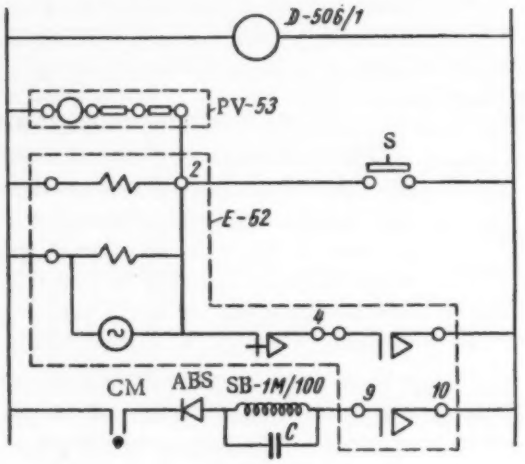


Fig. 1.

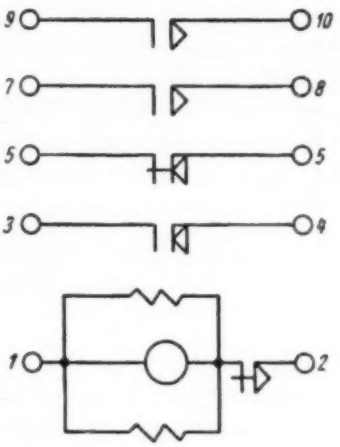


Fig. 2.

The operation of the instrument is based on the automatic count of pulses transmitted to the counting mechanism for each revolution of the machine rotor during a certain given period of time.

The instrument (Fig. 1) comprises a time relay E-52, a SB-1M/100 pulse counter, a contact mechanism CM, a switch K for starting the counter, and a rectifier ABS for the pulse counter.

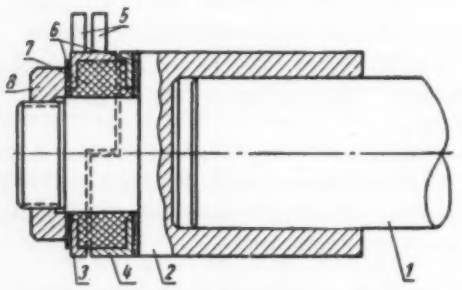


Fig. 3. 1) Shaft; 2) holder; 3) contact ring; 4) opposing ring; 5) brushes; 6) insulating washers; 7) insulating sleeve; 8) tightening nut.

A PV-53 electric timer and a D-506/1 frequency meter are used for adjusting the instrument and checking the accuracy of its operation.

The counter operates in the following manner.

When the switch button S is pressed, the time relay operates and, by its contacts 9-10 (factory identification), prepares the pulse counter circuit for the connection. For each revolution of the shaft, the counter adds a unit. After 60 sec, contacts 2-4 open and the counter stops. The number of units registered by the counter is the number of revolutions which the machine performed in one minute.

After each count, the counter can be again placed in zero position. The button has to be pressed for each new count.

The number of actual revolutions is determined according to the equation

$$n = n_1 \frac{60}{t_1} \cdot \frac{f_1}{50},$$

where $\underline{n}$ is the number of actual revolutions; n_1 is the number of counted revolutions; $\underline{t}$ is the time measured by the timer; f_1 is the frequency indicated by the frequency meter.

The standard model of the E-52 time relay is unsuitable for our instrument and must be modified as shown in Fig. 2. The factory identification of relay parts has been preserved in the figure.

Various constructions of the contact mechanism can be used, depending where it is mounted. It is only important that the pulse counter circuit be closed during a half-revolution. The construction of the mechanism which we used is shown in Fig. 3. In this construction, the holder is fitted snugly on the axle and fixed by a stopper screw to prevent slipping.

When the instrument is used for calibration, a shaft with two free ends, driven by a motor through an adjustable transmission, is used. The contact mechanism is fixed on one end of the shaft, and the tachometer to be checked, on the other end.

The described instrument secures an accuracy of 0.5.

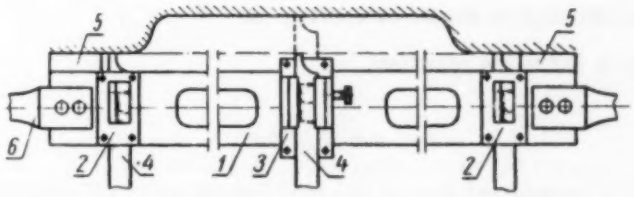
If, instead of a frequency meter and an electric timer, a single 521-V electronic timer is used, the error in the revolution count will be equal to 0.01%.

A DEFLECTION METER

A.M. Startsev

The deflection meter which has been developed by the author is intended for the measurement of the concavity and convexity of manufactured or repaired parts of large and small sizes.

The deflection meter (see figure) consists of a ruler 1, two fixed frames 2, and a sliding carriage 3 provided with a vernier with scale divisions equal to 0.1 mm. Bars 4 with millimeter divisions are placed in the frames and in the carriage. The bars are held tightly by means of springs. The length of bars depends on the magnitude of the deflection measured.



Holding plates 5, the edges of which must be in line with the edges of the bars when they are set to "0," are fastened at the ends of ruler 1. Handles 6 are fixed to the ends of ruler 1 for convenience in work.

The bars 4 are first set to "0", after which the deflection meter is placed on the part to be checked, then slider 3 is moved to the desired position, and, using bar 4, readings are taken.

For the measurement of convexity, the bars 4 are moved out of the fixed frames 2 to an equal distance greater than the convexity; the distance to the question in point is determined by moving the slider 3 and bar 4.

The convexity is determined as the difference in readings on the bars.

ON THE RELATION BETWEEN STATIC AND DYNAMIC CHARACTERISTICS OF HIGH-VOLTAGE SEMICONDUCTOR RECTIFIERS

K.B. Karandeev and N.G. Alfer'eva

If back currents have to be taken into account in the design of networks with semiconductor rectifiers, graphical and analytical methods based on the use of static characteristics of rectifiers can be applied as well as the method of dynamic half-wave characteristics [1] where the rectifier relation $I_{av} = f(U_{av})$, which is determined experimentally, is used.

The first methods are based on various approximations of static characteristics and they are connected with cumbersome and often complicated integrating operations. The second method eliminates integration, but requires a source of sinusoidal current pulses for the determination of the relation $I_{av} = f(U_{av})$ and the performance of rather painstaking experiments.

The advantages of the first method (the use of well-known characteristics of rectifiers) and those of the second (elimination of integration) can be used simultaneously by determining the relation between the static characteristic $i = f(u)$ and the dynamic half-wave characteristic $I_{av} = f(U_{av})$ of a rectifier.

The purpose of the present work is to establish the indicated relation for high-frequency semiconductor rectifiers. The present article also considers the most characteristic case where the application of the relation $I_{av} = f(U_{av})$ obtained for the forward and reverse directions of current through the rectifier is required – the calculation and the analysis of temperature conditions for the self-compensation of a symmetric bridge circuit with germanium rectifiers.

Usually, the calibration of rectifier circuits is performed for the sine form of the input quantity, where two different variants of the dynamic regime should be considered:

1) a sinusoidal voltage is fed to the rectifier:

$$u = U_m \sin \omega t;$$

2) a sinusoidal current is transmitted through the rectifier during a half-period:

$$i = I_m \sin \omega t.$$

The shape of the rectified current pulse is distorted to the greatest extent in the first case, and in the second case, it is sinusoidal; consequently, the $I_{av} = f(U_{av})$ curves, plotted for both conditions, will not agree. In actual instrument circuits, additional resistances of a few hundreds of ohms to several tens of kilohms are connected in series to rectifier components, due to which the voltampere characteristic of the whole circuit is linearized and the shape of the rectified current pulse is closer to the sinusoidal shape. Therefore, in the calculation of rectifier circuits, the dependence $I_{av} = f(U_{av})$ determined for the condition $i = I_m \sin \omega t$ should be used. In practice it can be considered that such conditions are established when an additional resistance $R_{ad} \geq 10r$ is connected in series to the rectifiers.

In this case, the dynamic half-wave characteristic is found by integrating the static characteristic of the form $u = f(i)$.

In considering the ohmic resistance of semiconductors and contact electrodes, it is known [2] that, due to the rather sharply defined "saturation" region, the static voltampere characteristic of a high-voltage crystal rectifier can be approximated in a wide range (from the maximum allowable current to a considerable intensity of the reverse voltages) by the following expression

$$i=I_0[e^{\kappa(u-ir)}-1], \tag{1}$$

where i is the current through the rectifier; I is the saturation current; k is the approximation factor; u is the voltage applied to the rectifier; r is the resistance of the semiconductor and of the contact electrodes.

The inverse function $u = f(i)$, which has to be integrated, is obtained by finding the logarithm of (1) after suitable transformations:

$$u=\frac{1}{\kappa}\ln\frac{i+I_0}{I_0}+ir. \tag{2}$$

Here, ir is the voltage drop across the ohmic resistance of the semiconductor; $\frac{1}{\kappa}\ln\frac{i+I_0}{I_0}$ is the voltage balancing the potential difference across the contacts.

For a voltage $U_{for} \geq 0.05$ v, $i \gg I_0$, and, therefore, for the forward branch of the characteristic, Eq. (2) will become simpler:

$$u=\frac{1}{\kappa}\ln\frac{i}{I_0}+ir. \tag{2a}$$

The expression (2a) is valid for the direct current as well as for instantaneous values of the alternating current; thus, for a sinusoidal current passing through the rectifier, we can write:

$$u=\frac{1}{\kappa}\ln\frac{I_m\sin\omega t}{I_0}+I_m\sin\omega tr,$$

or

$$u=\frac{1}{\kappa}\ln\frac{I_m}{I_0}+\frac{1}{\kappa}\ln\sin\omega t+I_m\sin\omega tr. \tag{3}$$

Then

$$U_{av}=\frac{2}{T}\left[\frac{1}{\kappa}\ln\frac{I_m}{I_0}\int_0^{\frac{T}{2}}dt+\frac{1}{\kappa}\int_0^{\frac{T}{2}}\ln\sin\omega t\,dt+I_m r\int_0^{\frac{T}{2}}\sin\omega t\,dt\right].$$

The first and the third integrals are determined in an elementary manner and the second is found from tables [3]; consequently:

$$U_{av}=\frac{1}{\kappa}\ln\frac{I_m}{I_0}-\frac{1}{\kappa}\ln 2+\frac{2}{\pi}I_m r. \tag{4}$$

The average voltage across the ohmic resistance of the semiconductor can be expressed in a different manner, using the average value of the rectified current I_{av} passing through the rectifier:

$$\frac{2}{\pi}I_m r=I_{av}r.$$

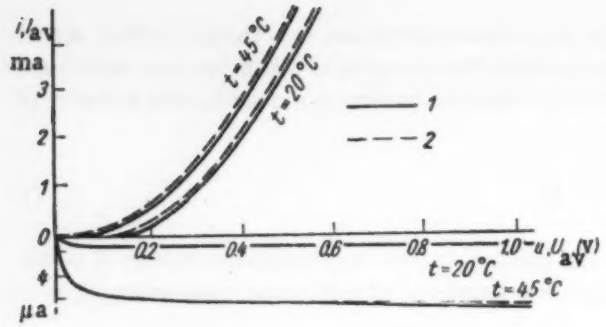


Fig. 1. 1) Static rectifier characteristic; 2) dynamic rectifier characteristic.

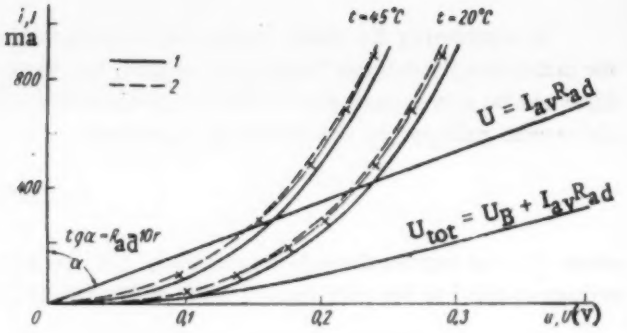


Fig. 2. 1) Experimental static characteristic; 2) experimental dynamic characteristic.

Then

$$I_m = I_{av}\frac{\pi}{2}.$$

Substituting I_{av} for I_m in (4), we obtain the relation $U_{av} = f(I_{av})$:

$$U_{av} = \frac{1}{\kappa}\ln\frac{I_{av}}{I_0} - \frac{1}{\kappa}\ln\frac{4}{\pi} + I_{av}r. \tag{5}$$

The inverse function $I_{av} = f(U_{av})$ for $U_{for} \geq 0.05$ v is of the form:

$$I_{av} = \frac{4}{\pi} I_0 e^{\kappa(U_{av} - I_{av}r)}. \tag{6}$$

It follows from (5) and (2a) that the dynamic half-wave current characteristic in the forward direction is shifted toward the region of lower voltages by the amount $\Delta U = \frac{\ln(4/\pi)}{k}$ with respect to the static characteristic. For a certain type of crystalline semiconductor rectifiers, the quantity k remains relatively unchanged (for instance, for point-contact high-voltage germanium rectifiers of the type DG-Ts1 or DG-Ts2, $k \approx 25$-35 1/v). Consequently, the mentioned shift ΔU is almost constant.

The reverse branch of the dynamic half-wave characteristic is almost coincident with the static characteristic. Actually, for the reverse current in (1), for $u_{rev} \leq 0.1$ v, $e^{-k(u-ir)} \ll 1$, and, consequently,

$$i_{rev} \simeq I_0 \simeq I_{av}. \tag{7}$$

It is known that the influence of temperature on the static rectifier characteristic is manifested by an exponential change of the saturation current [4]:

$$I_{0\theta} = I_0 e^{\alpha\Delta\theta},$$

where α is the temperature coefficient of the saturation current; $\Delta\Theta$ is the interval of temperature variations.

Substituting the value of $I_0\theta$ for I_0 in (6) and (7), we obtain the expression $I_{av} = f(U_{av}, \Theta)$ characterizing the dynamic operation of the rectifier under conditions where the load and temperature vary (for $U \geq 0.05$ v):

$$I_{av\,for} = \frac{4}{\pi} I_0 e^{\kappa(u_{av} - I_{av}r)} e^{\alpha\Delta\theta}; \tag{8}$$

$$I_{av\,rev} \simeq I_0 e^{\alpha\Delta\theta}. \tag{9}$$

Experimental investigations of static and dynamic characteristics of DG-Ts germanium rectifiers confirmed the validity of the obtained relations.

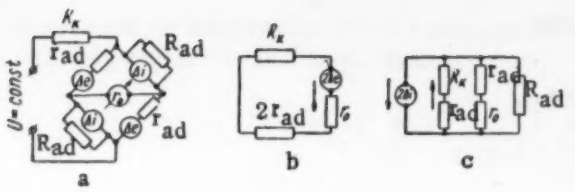


Fig. 3.

Figure 1 shows the direct and the reverse branches of static and dynamic half-wave characteristics of one of the DG-Ts1 rectifiers investigated, which were plotted experimentally for different temperatures.

For the rectifier mentioned, k = 26 1/v and I_0 = $= 1 \cdot 10^{-6}$ amp; consequently, the calculated value for

$$\Delta U = \frac{\ln(4/\pi)}{k} = 9 \text{ mv}.$$

According to experimental data, ΔU = (10-11) mv.

The respective shifts of dynamic and static characteristics are preserved when the temperature of the surrounding medium changes. The inverse branches of characteristics coincide.

Figure 2 shows the initial portion of the static and of the half-wave dynamic characteristic of the same rectifier, which is used in sensitive indicators.

The $I_{av} = f(U_{av})$ characteristic was obtained by subtracting from $U_{tot} = U_v + I_{av}r$ the voltage drop across the additional resistance R_{ad} = 10 r, which was connected in series to the rectifier during the experiment. As can be seen from Fig. 2, the shift ΔU remains almost unchanged along the characteristic.

In order to check the degree of agreement between the actual and the calculated half-wave characteristics obtained from (5), the characteristic $I_{av} = f(U_{av})$ was plotted for Θ = 20°C. For the values of I_0, k, and r, determined according to the actual static characteristic, the calculated and the experimental curves were almost coincident.

Thus, it can be stated that the theoretical results – Eqs. (8) and (9) – agree sufficiently well with experimental data and can be applied in the calculation of rectifier circuits. We shall demonstrate the possibility of such an application with an example where the conditions for the self-compensation of temperature errors of a symmetric bridge with DG-Ts1 rectifiers are calculated.

Let us take the temperature interval ΔΘ = 20°C and the maximum indicator current $I_{av\,max} = 100 \cdot 10^{-6}$ amp as the initial data in calculating the conditions for the self-compensation of temperature. Assuming that the indicator resistance $r_0 \ll r$, we shall neglect the influence of the surrounding medium temperature.

We shall determine the conditions for temperature self-compensation according to the method of equivalent circuits [5, 6].

The arms of the symmetric bridge circuit (Fig. 3a) contain equivalent emf's (Δe) and current sources (Δi) characterizing the temperature changes of the rectifier parameters.

According to the equivalent circuit in Fig. 3b, the intensification of current in the indicator, arising due to a change in the characteristics of the gating rectifiers with a change in Θ, is equal to:

$$\Delta I_{av\,for} = \frac{2\Delta e_{for}}{R_k + r_0 + 2r_v}.$$

The change of the current in the measuring device due to a change in the characteristics of shunting rectifiers (Fig. 3b) will be equal to:

$$\Delta I_{av\,rev} = \frac{2\Delta i_{rev}(R_k + r_v)}{R_k + r_0 + 2r_v}.$$

As the equality $\Delta I_{av\,for} = \Delta I_{av\,rev}$ is the condition for temperature self-compensation, we shall determine R_k by equating the corresponding expressions:

$$R_k = \frac{\Delta e_{for}}{\Delta i_{rev}} - r_v. \qquad (11)$$

The value of the equivalent emf in Eq. (11) is equal to:

$$\Delta e_{for}=\frac{dU_{for}}{d\Theta}\Delta\Theta,$$

the value of the equivalent current source is equal to:

$$\Delta i_{rev}=\frac{dI_{rev}}{d\Theta}\Delta\Theta,$$

the value of the differential rectifier resistance is equal to:

$$r_v=\frac{dU}{dI}\ \text{for.}$$

Consequently,

$$R_\kappa=\frac{\frac{dU_{for}}{d\Theta}}{\frac{dI_{rev}}{d\Theta}}=\frac{dU}{dI}\ \text{for.} \tag{11a}$$

The values for $dU_{for}/d\Theta$, $dI_{rev}/d\Theta$, and $(dU/dI)_{for}$ will be obtained by differentiating (8) and (9) with respect to the corresponding parameters:

$$\frac{dU_{for}}{d\Theta}=-\frac{a}{\kappa}\quad(\text{for}\ U_{for}>0,1s), \tag{12}$$

$$\frac{dI_{rev}}{d\Theta}=-aI_0e^{a\Delta\theta}, \tag{13}$$

$$\frac{dU}{dI}\ \text{for}=\frac{1}{\frac{4}{\pi}I_0\kappa e^{\kappa(U_{av}-I_{av}r)}}. \tag{14}$$

Substituting (12), (13), and (14) in (11a), we obtain:

$$R_\kappa=\frac{1}{\kappa}\left(\frac{1}{I_0e^{a\Delta\theta}}-\frac{1}{I_0e^{\kappa(U_{av}-I_{av}r)}}\right). \tag{11b}$$

Equation (11b) provides the possibility of not only determining the limits of self-compensation by possible parameters, but also of calculating the value for R_k in a simple manner.

The condition establishing the possibility of self-compensation is the inequality (see 11b):

$$\frac{1}{I_0e^{a\Delta\theta}}>\frac{1}{I_0e^{\kappa(U_{av}-I_{av}r)}}.$$

or [see (8), (9)]:

$$I_{rev\theta}<I_{for},$$

i.e., the conditions for the self-compensation of a symmetric rectifier bridge are almost unlimited.

Let us express R_k in terms of I_{for} and I_{rev}:

$$R_\kappa=\frac{1}{\kappa}\left(\frac{1}{I_{rev}e^{a\Delta\theta}}-\frac{1}{I_{for}}\right).$$

In this case, we shall use the DG-Ts1 point-contact high-voltage germanium rectifiers (α = 0.07 1/1° and k = = 25 1/v) with $I_0 = 2 \cdot 10^{-6}$ amp. Then,

$$R_k = \frac{1}{25}\left(\frac{1}{2\cdot 10^{-6}\cdot 2,7^{0.07\cdot 20}} - \frac{1}{100\cdot 10^{-6}}\right) \approx 5,4\cdot 10^3 \text{ohm}.$$

In order to obtain more accurate results, instead of using the differential value $dI_{rev}/d\Theta$, the average value $\Delta\Theta$ in the given interval should be used:

$$\frac{\Delta I_{rev}}{\Delta\Theta} = \frac{I_0(e^{\alpha\Delta\theta}-1)}{\Delta\Theta},$$

since, by using the differential value, we obtain a somewhat overly reduced value for the compensating resistance. The discrepancies between the theoretical and the experimental values for R_k are equal to 10-15% of R_k.

Analyzing (11b), we see that, for a symmetric bridge with germanium rectifiers, the conditions for temperature self-compensation depend on the interval of operating temperatures and on the voltage applied. For (u − ir) = const, i.e., when operating on the linear portion of the characteristic, and for $\Delta\Theta$ = const, the value for R_k remains unchanged; consequently, the compensation takes place within a certain interval on the scale of the instrument.

The calculation and the investigation of self-compensation conditions for other rectifier circuits are performed in a similar manner.

LITERATURE CITED

[1] A.Ya. Shramkov and Ya.E. Belen'kii, "Calculation of measuring circuits with semiconductor rectifiers by the method of dynamic half-wave characteristics," Coll.: Scientific Bulletin of the LPI (Leningrad Semiconductor Institute), Instrumentation Series, 2, 1958 [in Russian].

[2] Semiconductors, Theory and Application [Russian translation] ("Soviet Radio" Press, Moscow, 1952).

[3] I.M. Ryzhik, Tables of Integrals, Sums, Series, and Products [in Russian] (Moscow-Leningrad, 1948).

[4] J.S. Shaffner and R.F. Shea, "The variation of the forward characteristics of junction diodes with temperature," Proc. IRE No. 1, 43 (January, 1955).

[5] V.N. Mil'shtein, Élektrichestvo 5, 1950.

[6] K.B. Karandeev and L.A. Sinitskii, "On the temperature dependence of point-contact germanium rectifiers," Coll.: Doklady of the LPI (Leningrad Semiconductor Institute) vol. II, 1958 [in Russian].

A VISUAL METHOD OF DETERMINING THE NONLINEARITY OF SAWTOOTH VOLTAGE

D.I. Ataev

The existing methods of measuring the nonlinearity of sawtooth voltage (the method of standard oscillators, the method of the shift of scanning lines, etc.) do not secure a sufficient accuracy and speed in measurements.

The proposed method allows a quick, convenient, and more accurate determination of the nonlinearity of sawtooth voltage.

In the majority of cases, by nonlinearity of sawtooth voltage, we understand the change of its steepness with respect to the average steepness (Fig. 1):

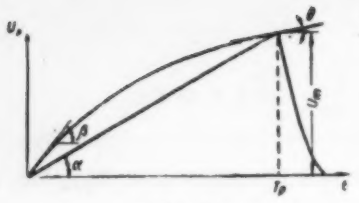


Fig. 1.

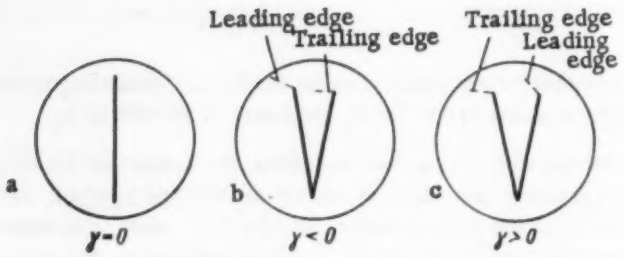


Fig. 3.

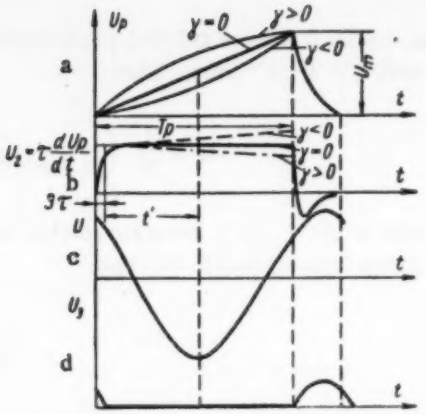


Fig. 2. Voltage diagrams explaining the formation of an electronic visor. a) The sawtooth voltage under investigation; b) voltage form after differentiation; c) scanning voltage; d) quenching pulse of the reverse sawtooth voltage.

$$\gamma = \frac{\left(\frac{dU_p}{dt}\right)_{t=0} - \left(\frac{dUp}{dt}\right)_{t=T_p}}{\left(\frac{dUp}{dt}\right)_{av}}, \tag{1}$$

where

$$\left(\frac{dUp}{dt}\right)_{t=0} = \operatorname{tg}\beta;\ \left(\frac{dUp}{dt}\right)_{t=Tp} = \operatorname{tg}\theta;$$
$$\left(\frac{dUp}{dt}\right)_{av} = \operatorname{tg}\alpha = \frac{U_m}{Tp}. \tag{2}$$

In the case where the sawtooth voltage is linear in the interval from t = 0 to t = Tp,

$$\frac{dUp}{dt} = k_0 = \text{const}. \tag{3}$$

We cannot judge the degree and the sign of nonlinearity by directly observing the sawtooth voltage on the screen of an oscillograph, as the nonlinearity of the scanning voltage of the oscillograph and the nonlinearity of the deflecting system of its tube are sources of large errors. The influence of these factors is eliminated when the sawtooth voltage derivative is considered.

If, after differentiating, a linear sawtooth voltage is fed to an oscillograph, pulses with flat horizontal peaks will be observed on its screen. If the sawtooth voltage is nonlinear, the flat peak of the observed pulse will have a positive or a negative slope, depending on the character of nonlinearity.

Thus, the nonlinearity of sawtooth voltage can be approximately evaluated by observing its slope on an oscilliograph.

For more accurate measurements, it is necessary to eliminate errors due to the parallax and inaccuracies in aligning the flat top of the differentiated pulse with a mechanical visor. An "electronic visor" can be used for this purpose.

The second beam of a double-trace electron oscillograph can serve as the electronic visor. However, sufficiently accurate measurements can be performed without the application of a double-trace oscillograph.

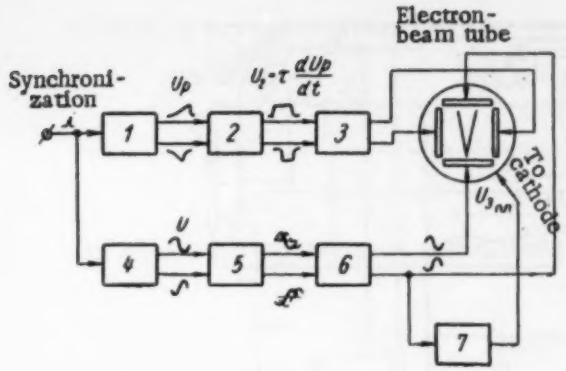


Fig. 4. 1) Sawtooth voltage generator; 2) differentiating circuits; 3) linear amplifier; 4) sinusoidal scanning oscillator; 5) phase inverter; 6) push-pull amplifier; 7) shaping circuit.

Fig. 5.

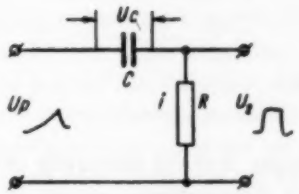


Fig. 6.

The method consists in measuring the difference between the slopes of the sawtooth voltage at the beginning and at the end of a sawtooth pulse by means of an electron-beam tube.

In this, the voltage of a triangular or sinusoidal shape can be used for the beam scanning.

The differentiated pulse is fed to the horizontal plates of the electron-beam tube and the scanning voltage of a triangular or sinusoidal shape is fed to the vertical plates.

These voltages should be made to coincide in time as shown in Figs. 2b and 2c.

Then, during the time t', the beam will move downward, and during the time Tp − t' upward.

In the case of a linear sawtooth voltage ($\gamma = 0$ — see Fig. 2a), a vertical line will be observed on the screen of the electron-beam tube (Fig. 3a).

If the sawtooth voltage is nonlinear, the beam will trace divergent lines (Figs. 3b and 3c).

In practice, it is convenient to use sinusoidal voltage for scanning, as it is much easier to obtain than the triangular.

The block diagram of the measuring device is shown in Fig. 4.

The sinusoidal scanning oscillator is synchronized by a voltage synchronous with the voltage under investigation.

After passing through the phase inverter and the amplifier, the sinusoidal voltage is fed to the vertical plates of the electron-beam tube. The sawtooth voltage under investigation is fed, after differentiation and linear amplification, to the horizontal plates of the electron-beam tube.

The phase of the sinusoidal scanning voltage is adjusted in such a manner that the maximum or the minimum of the sinusoidal voltage approximately corresponds to the time Tp/2 (see Fig. 2).

During the course of time corresponding to the trailing edge of the sawtooth voltage the beam is quenched by a specially formed pulse (Fig. 2d).

The steepness of the leading edge of the pulse at the output of the differentiating circuit will be always smaller than the steepness of the trailing edge, since the trailing edge of sawtooth voltage is always steeper than the leading edge. This circumstance makes it easier to determine the sign of nonlinearity of γ.

For a given direction of motion of the beam across the screen of the electron-beam tube, the sign of nonlinearity is determined according to the following principles.

If the leading edge of the sawtooth voltage derivative is located to the left of the trailing edge on the screen, the nonlinearity is negative (Fig. 3b), and, conversely, if the trailing edge is located more to the left, the nonlinearity is positive (Fig. 3c).

The accuracy of this measurement method is mainly determined by the resolving power of the measuring circuit.

Let us derive, according to the measurement results, the relations determining the nonlinearity of sawtooth voltage, and define the accuracy of the method.

Figure 5 shows the pattern traced by the electron-beam on the screen of an electron-beam tube in the case where the sawtooth voltage is nonlinear.

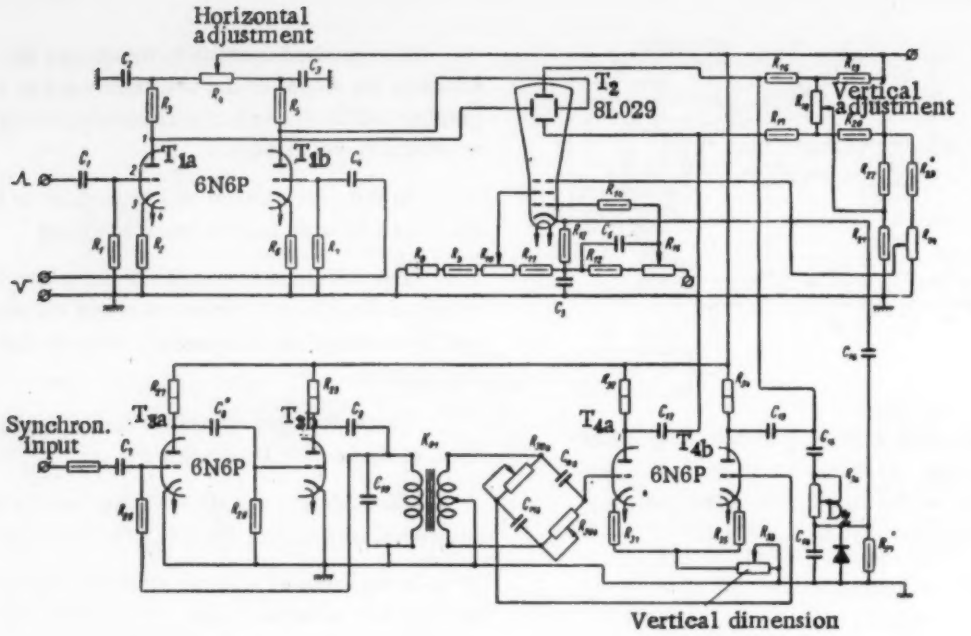


Fig. 7.

Let us introduce the following notation:

K is the amplification factor of the derived sawtooth voltage; S is the sensitivity of the horizontal plates in the electron-beam tube, mm/v; τ is the time constant of the differentiating circuit ($\tau = RC \ll Tp$); a is the beam thickness in mm.

Let us write (1) in the following form by taking into account the time necessary for the establishment of the derivative in the actual differential circuit ($t_y \simeq 3\tau$):

$$\gamma = \frac{\left(\frac{dUp}{dt}\right)_{t-3\tau} - \left(\frac{dUp}{dt}\right)_{t-Tp}}{\left(\frac{dUp}{dt}\right)_{av}} = \frac{\Delta\frac{dUp}{dt}}{\left(\frac{dUp}{dt}\right)_{av}} . \tag{4}$$

The value of $\Delta(dUp/dt)$ is determined by the distance Δl (see Fig. 5).

The relations between these quantities can be established by considering the diagram of the differential circuit (Fig. 6).

As $\tau \ll Tp$ (condition for differentiating),

$$iR \ll Uc\ ,\quad U_2 \simeq RC\frac{dUp}{dt} = \tau\frac{dUp}{dt} . \tag{5}$$

The distance Δl corresponds to the change in voltage U_2 at the output of the differentiating circuit during the time Tp:

$$\Delta l = KS\tau\Delta\frac{dUp}{dt} . \tag{6}$$

whence:

$$\Delta\frac{dUp}{dt} = \frac{\Delta l}{KS\tau} . \tag{7}$$

Substituting expressions (7) and (2) in (4), we obtain:

$$\gamma = \frac{\Delta \frac{dUp}{dt}}{\left(\frac{dUp}{dt}\right)_{av}} = \frac{\Delta l Tp}{KS\tau U_m} . \qquad (8)^*$$

The error due to the inaccurate measurement of Δl is equal to:

$$\Delta\gamma_{\Delta l} = \frac{Tp}{KSU_m\tau} \Delta(\Delta l). \qquad (9)$$

In the worst case, the value for $\Delta(\Delta l)$ is equal to the thickness a of the beam:

$$\Delta\gamma_{\Delta l\max} = \frac{Tpa}{KSU_m\tau} . \qquad (10)$$

The circuit diagram of the measuring device is shown in Fig. 7.

The push-pull sawtooth voltage is supplied through the differentiating circuits C_1R_1 and C_4R_7 to the input of a push-pull amplifier L_1 with a flat frequency response to direct current of a frequency of 50 kc. This characteristic of the amplifier permits the distortion-free transmission of the flat peak of the differentiated pulse. The anodes of tubes L_{1a} and L_{1b} are directly connected to the horizontal plates of the electron-beam L_2. The pulses synchronizing the sawtooth voltage generator are fed to the grid of L_3 of the sinusoidal voltage generator. This generator is constructed as a multivibrator with a feedback-encompassed circuit. The application of a circuit encompassed by feedback provided the possibility of considerably broadening the synchronization band for output signal frequencies higher than the natural frequency of the K_{01} circuit.

From the secondary winding of the K_{01} circuit, after passing through the phase inverter bridge, the push-pull sinusoidal voltage is fed to the input of the terminal deflection amplifier L_4. The output voltage of this amplifier is fed to the vertical plates.

The circuit shaping the beam quenching voltage consists of a phase-shifting circuit R_{36}, C_{14} and of a limiting diode D_1. The resistor R_{37} serves for establishing the limiting level.

The shaped quenching pulse is fed to the cathode of tube L_2.

For the established circuit parameters, the frequency of the sawtooth voltage can be varied by ±250 cps.

In order to change the range of operating frequencies in the circuit, it is necessary to change the time constants of the differentiating circuits C_1-R_1 and C_2-R_7, the parameters of the K_{01} circuit and one of the elements in the feedback circuit of the multivibrator (for instance, C_8). As an example, let us evaluate the error in determining the over-all correction for nonlinearity for the following parameters:

$$Tp = 500\ \mu\text{sec}, \quad K = 28, \quad \tau = 10\ \mu\text{sec},$$
$$S = 0.29\ \text{mm/v}, \quad U_m = 400\ \text{v}, \quad a = 0.5\ \text{mm},$$

$$\Delta\gamma_{\max} = \frac{500 \cdot 10^{-6} \cdot 0.5}{28 \cdot 0.29 \cdot 400 \cdot 10 \cdot 10^{-6}} \simeq 0.8 \cdot 10^{-2} .$$

The nonlinearity of the initial section of sawtooth voltage [$t \leq (3\text{-}5)\ \tau$] cannot be controlled by this method, as the stabilization of transient processes in the differentiating circuit takes place in this region. This limitation is not important since, in the first place, τ can be chosen in such a manner that the duration of transient processes constitutes 1-5% of the sawtooth voltage duration, and, in the second place, the initial portion of the sawtooth voltage is, as a rule, the most linear portion.

*The relation (8) is approximate, as the approximate Eq. (5) was used in its derivation. The error in expression (8) is due to the fact that it does not take into account the initial value of the derivative, but its value at a certain moment $t_{in} \neq 0$. For $t_{in} = 3\tau$, the error in determining γ according to (8) will be approximately equal to 5%, and for $t_{in} = 5\tau$, it will be 0.7%.

The condition $5\tau \ll Tp$ imposes a limitation on the upper limit of the measurement frequency range, as the presence of parasitic capacitance does not permit us to reduce τ at will.

By careful mounting, the upper limit of the frequency range can be boosted to 80-100 kc.

MEASUREMENT OF IMPEDANCES AT AUDIO FREQUENCIES BY THE METHOD OF MAGNETICALLY COUPLED CIRCUITS

O.G. Malkina

In a number of industrial processes (for instance, in the quality control of cable and condenser paper, inductances for radio equipment, etc.), it is necessary to control separately the R and X components of impedance Z. The complexity of existing methods of measuring impedance components slows down the control and automation in industrial processes where such measurements are required.

For the performance of isolated measurements (separate measurements of R and X), it is necessary to have circuits with different sensitivities to changes in resistance and reactance, which can be achieved by means of magnetically coupled circuits.

Figure 1 shows circuits with magnetically coupled windings with negative magnetic couplings.

The currents in circuits can be found by solving the following system of equations:

$$\left.\begin{aligned} \dot{U}_c &= \dot{I}_1 R_1 + j X_1 \dot{I}_1 + \dot{I}_1(\Delta R \pm j\Delta X) - j X_M \dot{I}_2 , \\ \dot{U}_c &= \dot{I}_2 R_2 + j X_2 \dot{I}_2 + j X_M \dot{I}_1 \end{aligned}\right\} \quad (1)$$

For identical and directly connected windings

$$\left.\begin{aligned} R_1 &= R_2 = R , \\ X_1 &= X_2 = X = \omega L , \\ \Delta Z &= \Delta R \pm j\Delta X = 0 , \\ X_M &= X \end{aligned}\right\} \quad (2)$$

the currents in loops are equal and they are in phase with the feeding voltage:

$$\dot{I}_1 = \dot{I}_2 = \frac{\dot{U}_c}{R} . \quad (3)$$

The resistance of each loop is equal to R for any inductance L of the magnetically coupled windings.

If a small impedance $\Delta Z = \Delta R \pm j\Delta X \neq 0$ is connected to one of these circuits, the currents will change. In this case, the currents will be equal to:

$$\left.\begin{aligned} \dot{I}_1 &= \frac{\dot{U}_c}{R + \Delta R \pm j\Delta X - \Delta R \frac{2X^2}{R^2+4X^2} \pm \Delta X \frac{RX}{R^2+4X^2} - j\Delta R \frac{RX}{R^2+4X^2} \mp j\Delta X \frac{2X^2}{R^2+4X^2}} , \\ \dot{I}_2 &= \frac{\dot{U}_c}{R + \Delta R \frac{(2X \pm \Delta X)X}{(R+\Delta R)^2+(2X\pm\Delta X)^2} \mp \Delta X \frac{(R+\Delta R)X}{(R+\Delta R)^2+(2X\pm\Delta X)^2} + j\Delta R \frac{(R+\Delta R)X}{(R+\Delta R)^2+(2X\pm\Delta X)^2} \pm j\Delta X \frac{X(2X\pm\Delta X)}{(R+\Delta R)^2+(2X\pm\Delta X)^2}} . \end{aligned}\right\} \quad (4)$$

Equations (4) show that the active components of impedances changed, and reactive components appeared. For

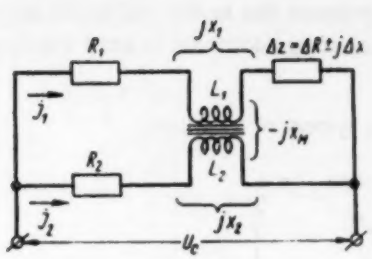


Fig. 1.

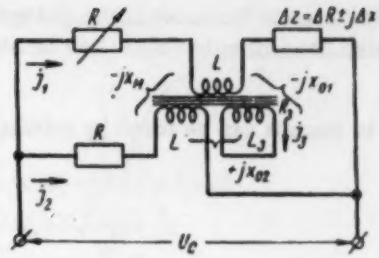


Fig. 2.

small impedances ΔZ, when the reactive components of impedances are considerably smaller than the active components and the resistance moduli of circuits are almost exclusively determined by the active components,

$$\Delta R \ll R;\ \Delta X \ll R, \tag{5}$$

The moduli of currents will be equal to:

$$\left.\begin{aligned} |I_1| &\simeq \frac{|\dot{U}_c|}{R+\Delta R-\Delta R\dfrac{2X^2}{R^2+4X^2} \pm \Delta X\dfrac{RX}{R^2+4X^2}}; \\ |I_2| &\simeq \frac{|\dot{U}_c|}{R+\Delta R\dfrac{(2X+\Delta X)X}{(R+\Delta R)^2+(2X+\Delta X)^2} \mp \Delta X\dfrac{(R+\Delta R)X}{(R+\Delta R)^2+(2X+\Delta X)^2}} \end{aligned}\right\} \tag{6}$$

The scalar impedance of the first circuit will change only by ΔR for small inductances of magnetically coupled windings (i.e., for $L \to 0$) when the impedance ΔZ to be measured is connected. With an increase in L, the change of the impedance modulus due to ΔR will decrease, and the change due to ΔX will increase. Thus, by changing the inductance L of magnetically coupled circuits, it is possible to regulate the respective current variations due to the ΔR and ΔX components of the impedance to be measured.

The change in scalar impedance caused by introducing ΔZ in the circuit can be compensated for by a reverse change of the active circuit resistance by Δr (for instance, by regulating the resistance of a resistance box connected to the circuit), making it thereby again equal to R.

The change in resistance can be found from the equation:

$$\Delta r\left[1-\frac{2X^2}{R^2+4X^2}\right]=\Delta R\left[1-\frac{2X^2}{R^2+4X^2}\right]\pm\Delta X\frac{RX}{R^2+4X^2}. \tag{7}$$

For $L \to 0$, the change in resistance will be equal to ΔR. For large inductances L, the resistance will change by

$$\Delta r=\Delta r_1+\Delta r_2, \tag{8}$$

where $\Delta r_1 = \Delta R$ and

$$\Delta r_2=\pm\left[\Delta X\frac{RX}{R^2+4X^2}\right]:\left[1-\frac{2X^2}{R^2+4X^2}\right]=\pm\Delta X\frac{RX}{R^2+2X^2}.$$

In this case, the difference in active resistances will be compensated by a change equal to Δr_1, and the component due to ΔX, by an additional change in resistance equal to Δr_2.

The additional change in resistance Δr_2 for a given circuit with certain values for R and L is proportional to ΔX. For the inductive components of impedance ΔZ, Δr_2 is positive, and for capacitive components, it is negative.

In circuits with large inductances L, the change in scalar impedance due to the additional impedance ΔZ to be measured, which depends only on ΔR, can be obtained by connecting additional shorted windings, as shown in Fig. 2.

The currents in circuits can be found by solving the following system of equations:

$$\left.\begin{aligned} \dot{U}_c &= \dot{I}_1 R + jX\dot{I}_1 - jX_M\dot{I}_2 + \dot{I}_1(\Delta R \pm j\Delta X) + jX_{01}\dot{I}_3; \\ \dot{U}_c &= \dot{I}_2 R + jX\dot{I}_2 - jX_M\dot{I}_1 - jX_{02}\dot{I}_3; \\ 0 &= \dot{I}_3 R_3 + jX_3\dot{I}_3 + jX_{01}\dot{I}_1 - jX_{02}\dot{I}_2. \end{aligned}\right\} \tag{9}$$

If the natural resistance of the shorted winding is equal to zero ($R_3 = 0$) and the windings are connected directly, i.e., if

$$\left.\begin{aligned} X_M &= X; \\ X_{01} &= X_{12} = \sqrt{XX_3} \end{aligned}\right\}, \tag{10}$$

the currents in the circuits will be:

$$\left.\begin{aligned} \dot{I}_1 &= \frac{\dot{U}_c}{R + \Delta R \pm j\Delta X}, \\ \dot{I}_2 &= \frac{\dot{U}_c}{R}. \end{aligned}\right\} \tag{11}$$

If (5) is satisfied, the absolute value of the current in the first circuit will be equal to

$$|\dot{I}_1| \simeq \frac{|\dot{U}_c|}{R + \Delta R}. \tag{12}$$

Thus, when additional shorted windings are present in the circuits, the change in the active circuit resistance necessary for compensating the change in the scalar impedance will correspond to resistance ΔR. After the shorted winding is disconnected, the subsequent change of the active current resistance will be proportional to ΔX.

When impedances are measured by the method of magnetically coupled circuits, the leakage reactance must be also much smaller than the resistance R.

If, for higher frequencies, the inductive reactance increases to a large value, it can be compensated for by a capacitive reactance.

In this case, the current in the first circuit without a shorted winding will be equal to

$$\dot{I}_1 = \frac{\dot{U}_c}{R + jX - jX_c - jX_M + (\Delta R \pm j\Delta X)\dfrac{R + j(X - X_c)}{R + j(X - X_c + X_M)}}. \tag{13}$$

If a shorted winding is present, the current will be

$$\dot{I}_1 = \frac{\dot{U}_c}{R + jX - jX_c - jX_M + (\Delta R \pm j\Delta X)\dfrac{R + j(X - X_c) - jK_{mu}^2 X}{R + j(X - X_c + X_M) - j2K_{mu}^2 X}}, \tag{14}$$

where K_{mu} is the coefficient of coupling of a circuit with a shorted winding.

In order to measure the active component of the impedance in question, the coefficient of impedance $\Delta Z = \Delta R \pm j\Delta X$ in (14) must be approximately equal to 1. This is possible under the condition where

$$X - X_c + X_M - 2K_{mu}^2 X \ll R. \tag{15}$$

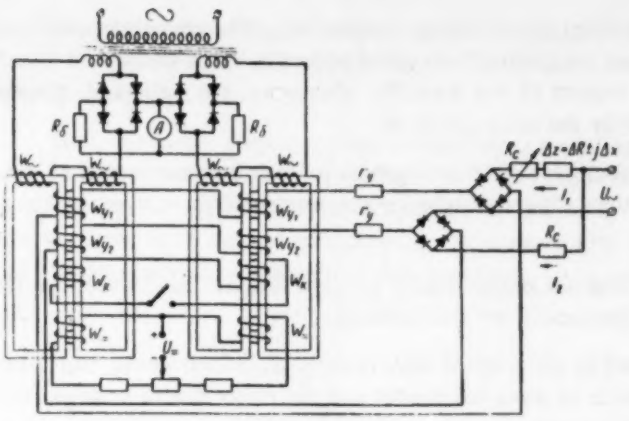


Fig. 3.

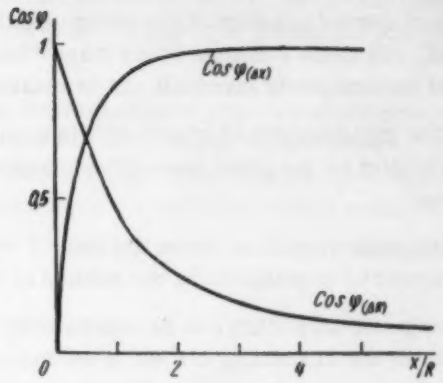


Fig. 4. $X = 2\pi f \Sigma L_{y2} = 2\pi f \Sigma L_{y1}$, where f is the frequency of the control network feed source.

For directly connected windings and a natural resistance of the shorted winding equal to R_3, the current in the first circuit will be equal to

$$\dot{I}_1 = \frac{\dot{U}_c}{R + (\Delta R \pm j\Delta X)\dfrac{R(R_3 + jX) + jR_3X}{R(R_3 + jX) + j2R_3X}}. \tag{16}$$

In this case, the coefficient of ΔZ must also be approximately equal to 1.

This is possible if the following inequalities are satisfied

$$\left.\begin{array}{l} R_3 \ll X, \\ R_3 \ll R \end{array}\right\}. \tag{17}$$

If conditions (5) are satisfied, the change in the circuit impedance due to the connected impedance to be measured will always be small. It can amount to fractions of one percent. In order to measure ΔR and ΔX in which we are interested with an accuracy of a few percent, it is necessary that the measuring instrument reacts to changes in impedance equal to thousandths of one percent.

In practice, such accuracy can be obtained with instruments directly indicating an increase in the quantities which are being measured. For instance, instruments where the readings are proportional to the difference between the absolute values of currents in the circuits can be used for this purpose. When shorted windings are present, the instrument readings will be proportional to the active component of the impedance measured, since

$$\Delta i_1 = |\dot{I}_2| - |\dot{I}_1| = |\dot{I}_1|\frac{\Delta R}{R}. \tag{18}$$

If no shorted windings are present, the instrument readings will depend on ΔR as well as on ΔX, but the greater the inductance of magnetically coupled windings, the greater the relative sensitivity to changes in ΔX, since

$$\Delta i_2 = |\dot{I}_2| - |\dot{I}_1| \simeq |\dot{I}_1|\frac{\Delta RR \pm \Delta XX}{R^2 + X^2}. \tag{19}$$

The described method can also be used for the measurement of small resistances of specimens made of magnetically soft materials. Due to the nonlinearity of the relation between induction B and the intensity magnetic field H in ferromagnetic materials, the resistance of the specimen under investigation depends on the intensity of the magnetization current.

For small changes in the magnetizing current (of the order of 1%), the changes in resistances ΔR and ΔX

in specimens of magnetically soft ferromagnetic materials will not be noticeable. The connection and disconnection of shorted windings in the above-mentioned magnetically coupled networks, when conditions (5) are satisfied, will cause a change in the magnetizing current of less than 1%. Therefore, the resistance of specimens made of ferromagnetic materials can be measured by the same methods.

The measurement of impedances in small specimens of ferromagnetic materials in the region of the largest permeabilities by the given method – when conditions (5) are satisfied – are performed for a sinusoidal magnetizing force.

Magnetic amplifiers where the control windings are magnetically coupled circuits can be used for the measurement of impedances by the method of magnetically coupled circuits.

Magnetic amplifiers can be conveniently used in differential circuits (Fig. 3), which would eliminate the distortion of the alternating current in control circuits by even harmonics and the errors due to voltage fluctuations and also secure a zero current at the amplifier output when the resistance to be measured is absent.

The circuit in Fig. 3 is equivalent to an instrument which reacts to the average value of the current intensity and where the current difference is used for measurements; this current difference is limited by the half-period of the current I_1.

If a shorted winding is present, the current difference will be equal to

$$\Delta\dot{I}=\dot{I}_2-\dot{I}_1=\frac{\dot{U}_c}{R}-\frac{\dot{U}_c}{R+\Delta R\pm j\Delta X}=\dot{I}_1\frac{\Delta R}{R}\pm j\dot{I}_1\frac{\Delta X}{R}, \tag{20}$$

where R is the total active resistance of the circuit ($R = R_c + r_y$).

This current consists of a component proportional to ΔR which is in phase with current $\dot{I}_1$, and a component proportional to ΔX and shifted by 90° with respect to current $\dot{I}_1$. Therefore, when the passage of the current difference through the instrument is limited by the half-period of the current $\dot{I}_1$, its average value will be proportional only to ΔR.

If a shorted winding is not present, the current difference for small ΔR and ΔX and for $\Delta X \ll X$, will be equal to

$$\Delta\dot{I}=\dot{I}_2-\dot{I}_1\simeq\frac{U_c}{R\pm j\Delta X}\left[\Delta R\frac{R-j2X}{R^2+4X^2}\pm\Delta X\frac{2X+jR}{R^2+4X^2}\right], \tag{21}$$

i.e.,

$$\Delta i\simeq\frac{I_{1\max}}{\sqrt{R^2+4X^2}}\left\{\Delta R\sin[\omega t-\varphi_{(\Delta R)}]\pm\right.$$
$$\left.\pm\Delta X\sin[\omega t+\varphi_{(\Delta X)}]\right\}, \tag{22}$$

where

$$\varphi_{(\Delta R)}=\operatorname{arctg}\frac{2X}{R},$$

$$\varphi_{(\Delta X)}=\operatorname{arctg}\frac{R}{2X}.$$

When the passage of the current difference through the instrument is limited by a half-period of current I_1, its average value will be equal to

$$\Delta I_{av}=\frac{I_{1\max}}{\pi\sqrt{R^2+4X^2}}\int_0^{\pi}\left\{\Delta R\sin[\omega t-\varphi_{(\Delta R)}]\pm\Delta X\sin[\omega t+\varphi_{(\Delta X)}]\right\}d\omega t=\frac{I_{1\max}}{\pi\sqrt{R^2+4X^2}}\left[\Delta R2\cos\varphi_{(\Delta R)}\pm\Delta X2\cos\varphi_{(\Delta X)}\right]. \tag{23}$$

Figure 4 shows the dependences of $\cos\varphi_{(\Delta R)}$ and $\cos\varphi_{(\Delta X)}$ on the ratio of parameters of the measuring circuit – the amplifier control circuit.

It is obvious from Fig. 4 that, for different circuit parameters, the dependence of instrument readings on ΔR and ΔX will be different, and the greater the inductance of control windings, the greater the relative sensitivity to changes in ΔX.

Thus, magnetic amplifiers can be used for the successive determination of impedance components. In this case, the active component of impedance is determined first when shorted windings W_k are present. After balancing (compensating) the active component (by changing the resistance R_c of the resistance box in one circuit) the disconnection of shorted windings W_k will cause a new deflection of the indicator, which would be proportional to the reactive component of the impedance to be measured.

MEASUREMENT OF ANGLE ERRORS OF MUTUAL INDUCTANCE COILS BY MEANS OF AN ALTERNATING CURRENT BRIDGE

A.Z. Veksler

In a number of cases, the mutual inductance coil is used for a highly accurate establishment of a 90° phase shift between the current and the voltage. A right-angle-coordinate potentiometer can be cited as an example.

The method of measuring the angle error in mutual inductance coils which has been described in [1] is based on the use of a capacitor with a small loss angle, of a nonreactive shunt, and a number of other components. Moreover, the slope of the capacitor loss angle must be known with a sufficiently high accuracy. Similar requirements are imposed on other standard devices used in this method. However, an alternating current bridge can be used for the determination of angle errors, which would permit the measurement of the resistance and inductance of coils.

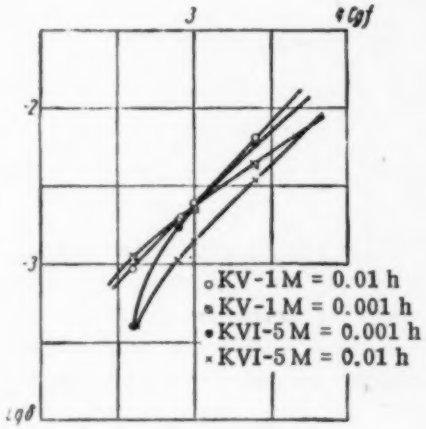


Fig. 1.

Method used in measuring the angle error. The angle error in mutual inductance coils leads to a situation where the angle of the phase shift between the emf induced in the secondary winding and the current in the primary winding is different from 90°. Let us denote the emf induced in the secondary winding by $\dot{E}_2$ and the current in the primary winding by $\dot{I}_1$. Then, taking into account the angle error, we obtain the relation

$$\dot{E}_2 = \dot{I}_1 (j\omega M + r) \qquad (1)$$

where M is the coefficient of mutual inductance.

Hence, the angle error is equal to

$$\delta \simeq \frac{r}{\omega M}. \qquad (2)$$

It should be noted that r is not a constant quantity and that it mainly depends on frequency and some other factors. The angle error is determined by a number of factors depending on frequency, including losses due to eddy currents in the windings and other parts of the coil, distributed interturn capacitance, and the insulation resistance, which are of particular importance.

As is known, an ac bridge, designed for the measurement of inductance coil parameters, can be used for determining the coefficient of mutual inductance. It can be easily shown that, under certain conditions, it can also be used for the measurement of angle errors of mutual inductance coils.

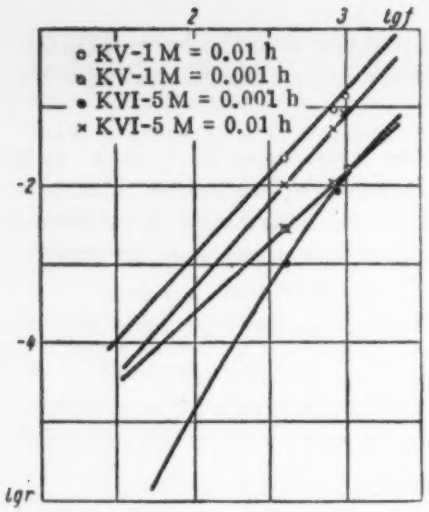


Fig. 2.

If we denote the inductance and the resistance of the first and of the second windings by L_1, r_1, L_2, and r_2, respectively, then, when the windings are connected in series in opposition, the voltage and the current in the coil are related by the following expression

$$\dot{U}_1=\dot{I}_1\ [j\omega\ (L_1+L_2-2M)+r_1+r_2-2\,r]. \tag{3}$$

For an accordant connection of windings in series, the current and the voltage are related by the expression

$$\dot{U}_2=\dot{I}_2\ [j\omega\ (L_1+L_2+2\ M)+r_1+r_2+2\,r]. \tag{3a}$$

The resistance $\underline{r}$ is equal to

$$\begin{aligned} R_1 &= r_1+r_2-2\ r, \\ R_2 &= r_1+r_2+2\ r. \end{aligned} \tag{4}$$

Hence

$$r=\frac{R_2-R_1}{4}. \tag{5}$$

The coefficient of mutual inductance can be calculated by means of the well-known equation

$$M=\frac{L''-L'}{4}, \tag{6}$$

where L' and L" are the inductances of the coil in the first and the second cases, respectively.

Thus, the angle error is equal to

$$\delta\approx\operatorname{tg}\delta=\frac{R_2-R_1}{\omega\ (L''-L')}. \tag{7}$$

Some errors in measuring δ. It is obvious th m (7) that the error in determining the angle depends on the accuracy in measuring $(L''-L')$ and (R_2-R_1). It should be noted that since L', L", R_1, and R_2 enter the equation in the form of differences (R_2-R_1) and $(L''-L')$, the values for the resistance and the inductance of both windings do not directly influence the measurement accuracy. As a rule, the relative error in measuring the difference $(L''-L')$ is of the same order of magnitude as the error in measuring the individual values for L' and L" and, by using highly accurate bridges, can be reduced to ±0.1%.

As for the error in measuring $\underline{r}$, it is determined by the sensitivity of the bridge to changes in R, changes in contact resistances at the terminals of the inductance coil, and reading errors. The resistance of connecting conductors, as well as other resistances connected in series to the mutual inductance coil, do not exert a direct influence on measurement errors, as they can affect the sensitivity of the circuit to a considerable extent. In the overwhelming majority of cases, the smallest possible resistance should be chosen as the additional resistance connected in series to the coil. In the UMPT-2 bridge, if M does not exceed 0.1 h, the indicator permits the detection of changes in resistance smaller than 0.001 ohm in the arm where the mutual inductance coil is connected. The reading error has approximately the same value. As for the changes in the contact resistance at the coil terminals when two measurements are performed, they can be reduced to a few ten-thousandths of an ohm in the overwhelming majority of cases. If we consider that the variation in readings of a resistance box rheochord connected in series to a mutual inductance coil does not exceed 0.005 ohm, the absolute error in the measurement of the difference (R_2-R_1) will be approximately equal to 0.01 ohm. Neglecting the error in measuring the mutual inductance, we shall obtain, in the given case, the following expression for the error in tanδ:

$$\Delta(\operatorname{tg}\delta) = \frac{0{,}0025}{\omega M}. \qquad (8)$$

Thus, for a coil with a mutual inductance of 0.01 h, for a frequency of f = 1000 cps, this error will be approximately equal to $5 \cdot 10^{-5}$ rad.

Results obtained in measuring the angle error of mutual inductance coils. The angle errors of mutual inductance coils KV-1 and KVI-5 were measured by means of the described method for the frequency range from 400 to 2500 cps. The curves in Fig. 1 show that the angle error steeply increases with an increase in frequency. This is easily understood if we take into account that the angle error of coils is determined by the interturn capacitance and losses due to eddy currents in copper conductors. A theoretical evaluation yields an approximately quadratic dependence of r on frequency (Fig. 2), which agrees with experimental data. As can be seen from the given curves, the angle error in coils changes from 0.01 to 0.001 for the indicated frequency range. If the obtained curves are extrapolated right up to f = 50 cps, the value for tanδ for the industrial frequency can be evaluated. This evaluation yields a magnitude of the order of 10^{-4} rad for the angle error of mutual inductance coils KV-1 and KVI-5.

SUMMARY

In using the described method for the measurement of angle errors of mutual inductance coils, it should be kept in mind that the error is determined by a number of factors, of which eddy currents in windings and the distributed capacitance are the most important. The presence of distributed capacitance leads to a situation where, in transition from the accordant connection of windings to connection in opposition, the leakage current changes. Therefore, the measured value of the angle error can be, generally speaking, substantially different from the value obtained if the given coil is used as an actual measure of the 90° phase shift. Consequently, the described method of measuring the angle error is suitable for those mutual inductance coils where the capacitance leakage is sufficiently small or does not change to a great extent when the coil connections are interchanged.

It should be remarked that this circumstance affects the measured value of the coefficient of mutual inductance to a certain extent if the measurement results are obtained by using (6).

Finally, we shall make another remark regarding the difference $(R_2 - R_1)$. In deriving (7), it was assumed that the resistance of both coils remained unchanged during the measurements. As the resistance corresponding to the loss angle is small, in order that the above condition be satisfied, it is necessary, in particular, to keep the temperature conditions of the coils under careful control by not overloading them with a current which would cause appreciable heating.

The requirement for the stability of resistances can be set forth in a concrete manner by assigning a certain given error Δ caused by their instability.

Denoting the change in resistance by δR, we obtain accordingly:

Thus, for R = 1000 cps, M = 0.01 h, and for $\Delta_1 = 5 \cdot 10^{-5}$, we have $\delta R = 3 \cdot 10^{-3}$ ohm.

LITERATURE CITED

[1] H.E. Linkch, ETZ 1952, 73, 153.

ON USING SILICON STABILITRONS FOR THE PRODUCTION OF STANDARD VOLTAGE

S.D. Dodik

Silicon stabilitrons (Zener diodes), which are used in various automation and measuring circuits, consist of silicon diodes manufactured by a special process. When they are reversed, for certain voltages and currents, an effect very similar to the firing of gas-discharge stabilizers takes place in the breakdown region. Here, in a given (Fig. 1), rather extensive range of current intensities, the stabilitron voltage remains almost constant. On one hand, this is connected with the phenomenon of impact ionization in solids, and, on the other hand, with the Zener effect where, under the influence of large field intensities, an avalanche-like increase of current carriers takes place due to a sharp increase in directional diffusion.

Figure 1 shows the voltampere characteristic of the D-808 stabilitron. It can be seen from the characteristic that, in the region of −8 v, if the current through the stabilitron changes from 1 to 20 ma, the stabilitron voltage remains almost unchanged. By analogy with gas-discharge tubes this region of the voltampere characteristic can be used for voltage stabilization.

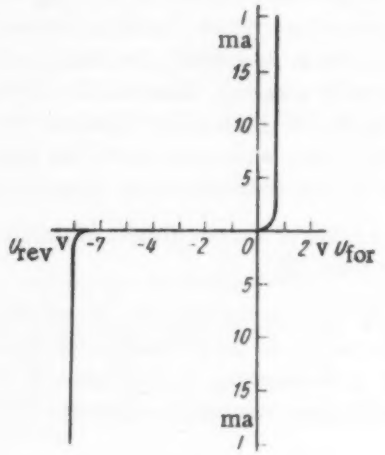


Fig. 1.

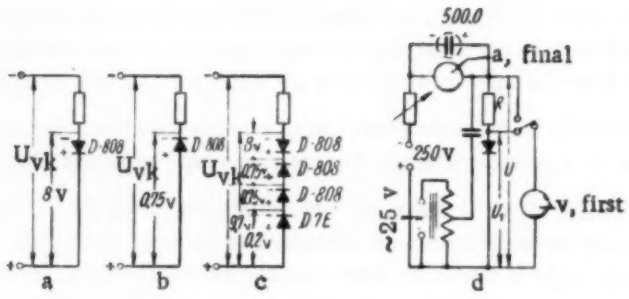


Fig. 2.

Silicon stabilitrons have a number of advantages in comparison with gas-discharge stabilizers:

1) By means of controlled variation of impurities in pure silicon and suitable production methods, they can be made for a voltage range from several volts to several hundreds of volts and for operating currents ranging from a few milliamperes to several amperes.

2) They do not have the so-called firing potential, which is higher than the stabilization voltage of gas-discharge stabilizers.

3) The decreasing region of the voltampere characteristic is absent, due to which capacitors of any capacitance can be connected in parallel to stabilitrons without the danger of self-excitation.

4) No discontinuous changes in the stabilization voltage can be observed.

5) "Aging," characterized by a slow irreversible change in the stabilization voltage, was not observed during the course of several thousands of hours.

6) When the operating conditions were kept constant, the stabilization voltage was accurately reproduced after a period during which the stabilitrons were switched off and on many times.

7) Silicon stabilitrons have small over-all dimensions and they can withstand larger impact overloads than the gas-discharge stabilizers.

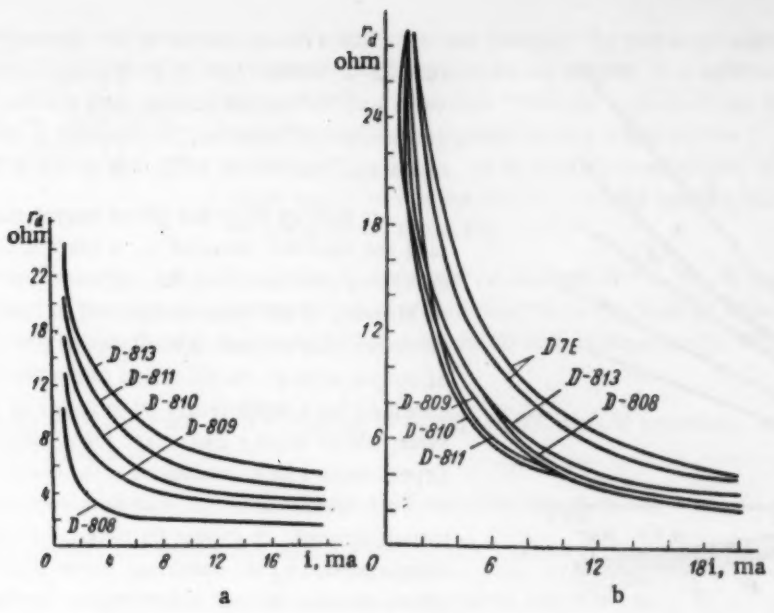


Fig. 3.

Stabilitron type	Polarity of connection	Voltage at 20°C, v
D-808	Reverse	7.2560
D-809	"	8.3246
D-810	"	9.3420
D-811	"	10.7475
D-813	"	12.4590
D-808	Forward	0.7400
D-809	"	0.7768
D-810	"	0.7580
D-811	"	0.7538
D-813	"	0.7631
D7E	"	0.2183
D7E	"	0.2211

8) The voltampere characteristic of stabilitrons (see Fig. 1) connected in the forward direction is such that, under the indicated conditions, they can be used as low-voltage (0.6-0.8 v) voltage stabilizers with a sufficiently small dynamic resistance. The temperature coefficient (TC) of forward-connected stabilitrons has the opposite sign with respect to TC of stabilitrons connected in the reverse direction. A comparatively large TC (+0.05 to +0.08%/°C) of available stabilitrons and, especially, of stabilitrons with comparatively large stabilization voltages, represents a certain drawback. However, this cannot reduce the usefulness of stabilitrons, as effective and sufficiently simple methods of temperature compensation are available.

This work presents the results of investigations performed on D-808–D-813 stabilitrons produced by domestic industry, the basic data on which are given in [1], with the aim of demonstrating the possibility of using them as standard voltage sources replacing the class III standard cells.

An example of a circuit where a stabilitron is connected in the reverse direction is given in Fig. 2a, and an example of the forward connection is given in Fig. 2b. A circuit with stabilitrons connected in series in the reverse and forward directions and with a germanium diode connected in the forward direction, in order to secure the temperature compensation, is shown in Fig. 2c.

The dynamic resistance r_d was determined for a 50-cps alternating current by means of a circuit shown in Fig. 2d.

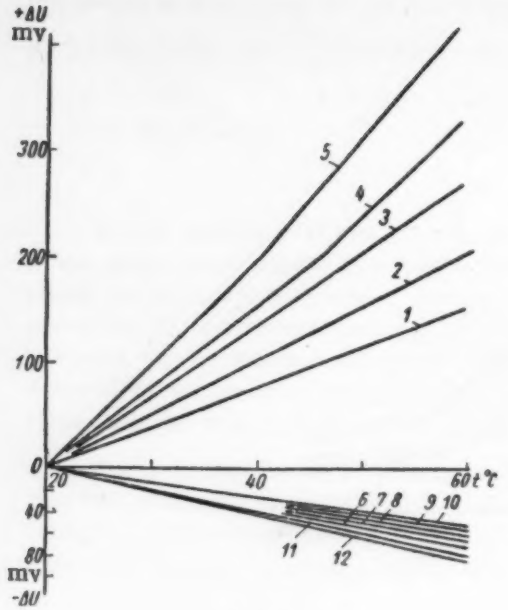


Fig. 4.

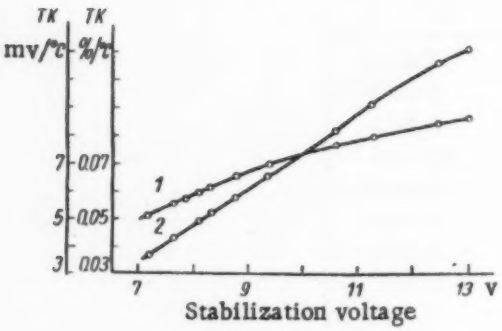


Fig. 5.

The average curves of the dependence of r_d on current for different types of stabilitrons connected in the reverse and forward directions, and also for forward-connected germanium D7E diodes, for currents in the range 1-20 ma and a temperature of 20°C, are given in Figs. 3a and 3b.

It follows from the given curves that, in order to obtain the smallest value of r_d, a current of the order of 10 ma should be considered as the optimum operating current for stabilitrons of all types connected in the reverse direction. However, this current is too large if the optimum coefficient of output voltage stabilization and a steady TC are to be obtained for a sufficiently wide range of positive temperatures, which is very important for temperature compensation. Experiments and calculations show that a current of the order of 5 ma should be considered as a compromise for the optimum current. It should be noted that the scatter of the characteristic r_d vs. operating curve is large for reversely connected stabilitrons belonging to the same group.

For all stabilitrons, the dynamic resistance is practically independent of temperature, in the +20 to +60°C temperature range.

Figure 4 shows the temperature dependences of voltage increments in reversely connected stabilitrons D-808–D-813 (curves 1-5), and that of the same stabilitrons and D7E germanium diodes connected in the forward direction (curves 6-12). The characteristics were plotted for an operating current of 5 ma. The table shows the stabilitron voltages at 20°C for a current of 5 ma.

Figure 5 shows the experimental dependence of the relative TC of reversely connected stabilitrons produced by domestic industry on the stabilization voltage (curve 1) and the dependence of the absolute TC on stabilization voltage (curve 2).

From curves in Fig. 4 (1, 2, 3, 4, and 5), it follows that reversely connected stabilitrons have a positive TC in the interval +0.05 to +0.085%, which is determined by the stabilization voltage (see Fig. 5). In the temperature interval +20 to +60°C, a linear dependence of the stabilization voltage increment with temperature can be observed, while a slight deviation from linearity occurs in the region of high temperatures (+50 to +60°C) for D-811 and D-813 stabilitrons which have an increased stabilization voltage. This is connected with a deterioration of heat exchange conditions at high temperatures due to an increase in the relative temperature of semiconductor transition.

In the case where the stabilitrons are connected in the forward direction (curves 6, 7, 8, 9, and 10), the stabilitrons have a negative TC of the order of −1.65 to −1.8 mv/°C, which constitutes approximately −0.24%/°C (see Fig. 4). The indicated TC changes slightly from one specimen to another.

The D7E germanium junction-type diodes connected in the forward direction (curves 11 and 12) have a negative TC of the order of −1.8 to −2 mv/°C, which constitutes approximately −0.75%/°C. In the case where stabilitrons and germanium diodes are connected in the forward direction, a linear dependence of the voltage increase on temperature can be observed.

It is obvious from the given temperature characteristics that, by a combined connection in series of silicon stabilitrons in the reverse direction, and of silicon stabilitrons or germanium junction-type diodes in the forward direction, and by individually selecting the elements, it is possible to obtain a certain kind of battery with a sufficiently small internal resistance where the voltage is almost independent of temperature.

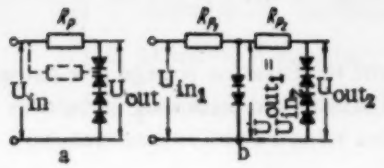


Fig. 6.

If stabilitrons are intended for use as reference voltage sources or stabilizers with semiconductor triodes, it is necessary to take into account the TC of the base–emitter section of the first cascade of the dc amplifier, which is approximately equal to the TC of a germanium junction-type diode. An approximate selection of stabilitrons and diodes to be connected in the forward and the reverse directions can be made by using curve 2 (see Fig. 5).

For an accurate adjustment of the TC, it is sometimes convenient to connect a resistance in parallel to stabilitrons and diodes connected in the forward direction. By selecting a suitable resistance, the current through the compensating elements and, consequently, TC, can be regulated within a limited range.

After the battery is constructed, it is advisable to check the TC and, if necessary, add or remove one or two forward-connected stabilitrons or diodes.

In temperature compensation, the following should be taken into account:

1) The current through the stabilitron must be steady at all times and it must be controlled.

2) All units of the compensated battery must be at the same temperature.

3) In compensation, the use of forward-connected stabilitrons is preferred to the use of forward-connected germanium diodes. This is due to the fact that the thermal inertia of germanium junction-type diodes is greater than that of silicon stabilitrons.

Ten batteries, each consisting of a reversely connected stabilitron and the necessary number of forward-connected stabilitrons or germanium diodes, were tested. The over-all TC of these batteries agreed very well with the algebraic sum of TC's of the component elements. Two batteries with voltages equal to 30.180 v and 27.618 v (20°C) and a TC close to zero also were constructed.

The first battery consisted of three reversely connected stabilitrons (2 x D-808 and D-809) and four stabilitrons and five D7E diodes connected in the forward direction. The second battery was composed of three reversely connected D-808 stabilitrons and four stabilitrons and three D7E germanium diodes connected in the forward direction.

For a current of 5 ma passing through the battery, the dynamic resistance of the first and second batteries was equal to 130 and 100 ohm, respectively. For a temperature change from +20 to +60°C, the voltage of the first and the second batteries changed from 30.180 to 30.170 v and from 27.618 to 27.626 v, respectively, i.e., the first battery had a negative TC smaller than −0.001%/°C, and the second battery had a positive TC smaller than 0.001%/°C. This indicates that, by applying temperature compensation, silicon stabilitrons can secure a better steadiness of the output standard voltage in dependence on temperature than the class III standard cells. At the same time, such batteries are characterized by a number of advantages with respect to standard cells:

1) The size of a stabilitron battery for 30 v is many times smaller than the size of a battery composed of standard cells for a similar voltage.

2) The internal dynamic resistance of such a battery is approximately equal to 100 ohm, while the internal resistance of a single class III standard cell for a voltage of the order of 1.018 v is equal to 600 ohm, and the internal resistance of a battery of standard cells for a similar voltage is approximately equal to 18 kohm.

3) A stabilitron battery can operate in a greater temperature interval than the class III standard cells which can operate only in the temperature range from +10° to +40°C.

4) The allowable load current for a stabilitron battery is considerably larger than that for class III standard cells.

5) Stabilitrons can operate in any position, while the standard cells must always be in the vertical position.

Stabilitron batteries constructed in such a manner can have a preliminarily assigned TC of a given sign for the purpose of compensating the TC of the opposite sign of various elements in the circuit which is fed by standard voltage.

The voltage of the investigated stabilitron batteries was established with an accuracy of 2-3 mv, 2-3 min after they were connected.

Measurements conducted during a period of a few months showed that the stabilization voltage of a battery composed of stabilitrons can be reproduced with an accuracy equal to that of the applied measuring instrument (the measurements were performed with a PPTV-1 class II potentiometer with a standard cell as a reference).

The stability of the two 30.180 v and 27.618 v batteries which we investigated was checked over a period of three months. The battery voltage changed by 2-3 mv during the course of a day. When the battery was connected after a month of inactivity, the voltage was established with an accuracy of ±3 mv.

When the 30.180 v battery was connected to the emitter of the amplifier triode of a high-quality stabilizer with semiconductor triodes, designed for the feed of potentiometers and measuring instruments, the output voltage of the stabilizer was reproduced and kept constant with an accuracy of ±4 mv over a long period of time (of the order of two months).

Practical application of silicon stabilitrons. Stabilitrons can be used in parametric stabilizers as well as in compensation stabilizers with semiconductor triodes [2-6].

Figure 6a shows the circuit of a single-stage parametric stabilizer with temperature compensation. The output resistance of this stabilizer is nearly equal to r_d. The temperature coefficient depends on the degree of temperature compensation and can be made equal to a magnitude of the order of ±0.001%/°C. It can be shown that the stabilization K of the output voltage can be expressed by the equation

$$K=\frac{U_{out}}{(I_0+I_l)r_d}\left(1-\frac{U_{out}}{U_{in}}\right),$$

where U_{in} and U_{out} are the input and output voltages of the stabilizer, respectively; I_0 is the operating current of the stabilitron; I_l is the load current of the stabilizer.

It is clear that I_0 must be made to be as small as possible, but several times larger than I_l.

In practice, in order to obtain K_{max}, it is sufficient to take $U_{in} \simeq (8\text{-}10)\, U_{out}$.

When using a D-808 stabilitron in the circuit shown in Fig. 6a, for I_0 = 5 ma, r_d = 2 ohm (reversed connection), r_d = 7 ohm (forward connection), and U_{out} = 10 v, we obtained $K_{max} \simeq 85$.

If the primary regulation of the power supply voltage cannot be effected or if a higher stability of the input voltage must be secured, it is convenient to use a two-stage stabilizing circuit (Fig. 6b). It is not advisable to apply temperature compensation in the first cascade of the stabilizer, as r_d then sharply increases. In this case, it is more convenient to take into account the temperature changes in the first cascade when the over-all temperature compensation of the circuit is carried out, especially, since the changes are reduced by a corresponding factor in the second stabilization range.

A two-stage stabilizer, having the same output resistance and TC as the sing-e cascade stabilizer (approximately 23 ohm and ±0.001%/°C, respectively), secures a stability of the output voltage within a range of ±0.001% (±0.1 mv) when the power supply voltage changes by ±10%. Such a stabilizer is equivalent to a battery consisting of 10 class III standard cells.

A considerable reduction of the output resistance of parametric stabilizers can be achieved by letting through the compensating stabilitrons and diodes an additional current through a separate resistance shown by dotted lines in Fig. 6a. This also provides the possibility of securing an accurate temperature compensation by regulating the current through the compensating elements within a small range.

LITERATURE CITED

[1] New Semiconductor Devices, Radio 11, 1958.

[2] D. Smith, Communication and Electronics 16, 645-649 (1955).

[3] P. Dobrinski, H. Knabe and H. Muller, NTZ 10, 4, 195-198 (1957).

[4] G. Meyer-Brötz, Elektronische Rundschau 11, 12, 376-377 (1957).

[5] H. Lennartz, Funktechnik 13, 441-445 (1958).

[6] F. Provost, L'onde Electrique 38, 374, 347-353 (1958).

MEASUREMENTS AT HIGH AND SUPER-HIGH FREQUENCIES

STEPPING UP THE INPUT RESISTANCE OF SEMICONDUCTOR AMPLIFIERS

G.N. Novopashennyi and P.V. Novitskii

A large resistance which increases the sensitivity of measuring instruments and reduces errors at low frequencies is often required at the input of amplifiers used in measurement techniques.

There is a definite opinion [1, 2] that an interstage series feedback should be used for stepping up the input resistance of amplifiers with semiconductor triodes. In the simplest cascade with such a circuit – the emitter follower – the input resistance is equal to

$$R_{in} \simeq R_e\, b,$$

where R_e is the load resistance of the emitter follower; b is the current amplification factor of the cascade in a circuit with a common emitter.

The amplification can be increased in this cascade by using either compound, i.e., doubled or trebled triodes, or an ordinary amplifier section, encompassed by deep negative feedback (Fig. 1). As R_{in} of an amplifier encompassed by negative feedback is equal to

$$R_{in} = R_{in1}(1 + k\beta),$$

where R_{in1} is the input resistance of the first cascade, for sufficiently large values of $k\beta$, it is possible to obtain $R_{in} \gg R_{in1}$.

In practice, for values of the amplification factor of a section equal to k_i = 5000-6000, $k\beta \simeq 50$-100.

$R_{in} \simeq$ 150-300 kohm. It was established by experiments that the value of R_{in} remains sufficiently stable in this case and depends only slightly on changes in amplifier feed voltage and signal frequency in the region of audio frequencies.

An investigation of compound triodes, performed in the Leningrad Polytechnical Institute, showed that they should be used only at temperatures up to +40°C because of large uncontrolled collector currents, arising at higher temperatures (Fig. 2).

The large initial current I_{k0} and the nonlinearity of $I_k = f(I_b)$ characteristics, which are peculiar to compound triodes at higher temperatures, can be reduced by compensating the initial current of the first triode (Fig. 3). The reduction of the initial current I_{k0} is achieved by using smaller resistances (Fig. 3a). However, for small values of R, the b coefficient of the doubled triode is reduced and the linearity of its characteristic becomes worse.

At the same time, in order that the relation $I_{k0} < I_{ka1}$ be satisfied (I_{ka1} = 5 ma for P1 triodes), the resistance R must be of the order of several hundreds of ohms. For such values of R, the coefficient b is equal to 200-400, while for separately connected triodes $b \simeq 50$.

The shunting action of resistance R can be reduced by connecting it to the plus terminal of a supplementary source (Fig. 3b).

The use of triodes connected as diodes (Fig. 3c) yields much better results in compensating the initial current I_{k0}. In this case, a value for the coefficient b of the order of 600-800 can be obtained.

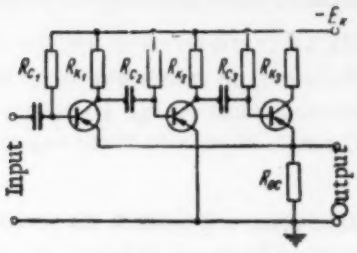


Fig. 1.

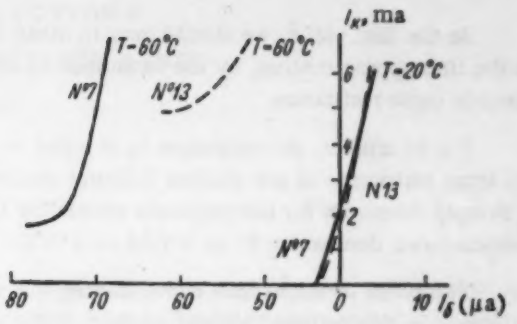


Fig. 2.

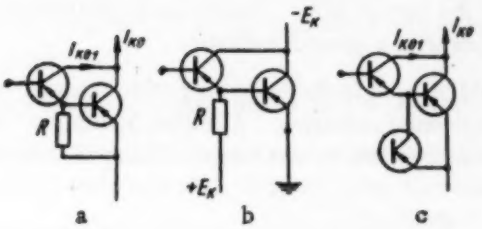


Fig. 3.

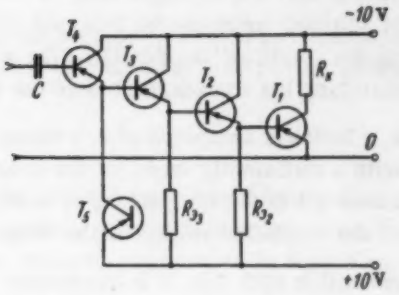


Fig. 4.

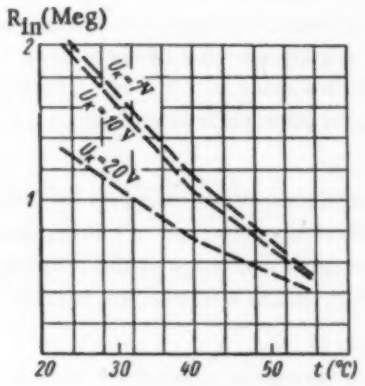


Fig. 5.

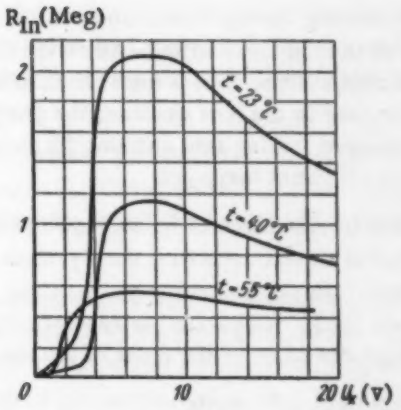


Fig. 6.

Two compensating elements for the compensation of initial currents should be provided in the trebled triode circuit. Such compound triodes actually consist of several emitter followers connected in series, the input resistance of which can be stepped up only by increasing the load resistance R_e.

As is known, the application of large load resistances leads to a considerable reduction of the triode voltage when the temperature increases, which causes distortions (limitation) of the signal to be amplified. As this reduction of voltage is a consequence of an increase in triode current, the load resistance must not exceed a few tens of thousands of ohms for a wide temperature interval.

Thus, in using P1A and P1E triodes for which the coefficient b is not less than 16, or P1Z triodes where $b > 24$, the input resistance can be 16-24 times as large as the load resistance (R_e) and reach a value of 300-500 kohm for $R_e \simeq 20$-30 kohm.

In the design of semiconductor amplifiers with a high input resistance, two circumstances should be taken into account.

In the first place, we should bear in mind that the base-collector resistance is a finite quantity determined, in the first approximation, by the resistance r_k of the collector junction, which is connected in parallel to the cascade input resistance.

For P1 triodes, the resistance r_k is equal to 0.3-0.5 meg. Therefore, no matter how large the product $R_e b$, the input resistance of the emitter follower cannot exceed the indicated values for r_k. Moreover, the value of r_k sharply decreases for temperatures exceeding the −40 to +40°C range, especially in the region of positive temperatures, decreasing 2- to 3-fold at +60°C.

The other circumstance complicating the production of a large input resistance is the fact that the load resistance of the emitter follower consists of the resistance connected to the emitter circuit of the triode, as well as of the resistance of the next amplifier cascade connected in parallel to it. If a cascade with a grounded emitter having an input resistance of the order of 1000 ohm is used as the next cascade, the input resistance of the emitter follower will not be larger than 16-24 kohm for b = 16-24. The above-mentioned input resistance of the order of 300-500 kohm can be obtained only if an iterated network of emitter followers connected to each other and to the amplifier cascade input (in order to simplify the circuit without transition capacitors) is provided for matching the impedance before the amplifier cascade with a grounded emitter.

Thus, a follower composed of 3-4 separate triodes should be used in the input amplifier cascade for an amplifier with a sufficiently large (of the order of 0.5-1.0 meg) input resistance. A further boosting of the input resistance requires the stepping-up of emitter load resistances, which, as was mentioned above, can cause a distortion of the amplified voltage if the temperature changes.

In connection with this, it is convenient to use a semiconductor triode of the required properties and with a cut-off base as the emitter load in the first cascade of emitter followers where it is especially important that R_e be large for the alternating current, and simultaneously small enough in order to secure a steady current.

Assuming the input resistance of the iterated network of emitter followers and the dynamic resistance of the triode used as the emitter load of the first cascade to be 0.3 meg, it can be taken that the resistance of the first cascade emitter load is equal to 0.15 meg. In this case, if a specially selected triode with r_k = 5 meg and $b \geq 24$ is used in the first cascade, the product bR_e can be increased to a value of 3.6 meg. The input resistance of the cascade, taking into account the shunting action of the collector junction resistance (r_k = 5.0 meg), will be equal to several megohms.

The circuit diagram for such an amplifier with a high input resistance is shown in Fig. 4. Here, the input resistance of the cascade with the T_1 triode is of the order of 1 kohm; it is stepped-up to a magnitude of 20 kohm by a follower consisting of the triode T_2 (R_{e2} = 10 kohm). The input resistance of the follower based on the triode T_3 ($R_e \simeq 60$ kohm) is approximately equal to 300-400 kohm, and,as a whole, the input resistance of the device should be of the order of 2.0 meg.

Practical tests performed on this amplifier showed that its input resistance exceeded 2 meg at 20° and its value decreased as the temperature rose (Fig. 5).

The dependence $R_{in} = f(U_k)$ has a clearly defined maximum (Fig. 6). The presence of a maximum is explained by the fact that the resistance r_k of the collector junction increases monotonically with a decrease in voltage, and for the interval U_k = 0-1 v, the resistance r_k is negligibly small.

SUMMARY

1. Semiconductor triodes provide the possibility of securing amplifier input resistances of the order of several hundreds of kilohms in a comparatively simple manner.

2. In practice, it is feasible to obtain amplifier input resistances of the order of several megohms, but the question whether the use of such amplifiers is advisable must be solved for each concrete case.

LITERATURE CITED

[1] R. Shi, Semiconductor Triodes and Their Application [in Russian] (GEI, 1957).

[2] E.V. Gershzon and I.F. Nikolaevskii, Semiconductor Triodes in Radio Broadcasting and Television Equipment Circuits [in Russian] (GEI, 1957).

CONSIDERATION OF MULTIPLE INTERNAL REFLECTIONS IN THE INVESTIGATION OF COMPLEX TRANSMISSION LINES COMPOSED OF SUPER-HIGH-FREQUENCY UNITS

K.I. Palatov

In evaluating the quality of a complex transmission line, i.e., if a large number of units, mismatched to various degrees, is present in the circuit, multiple internal reflections from individual inhomogeneities cannot be easily accounted for. Consequently, a number of simplifications must be introduced in order to solve this problem, and, as a result, exceedingly stringent requirements are imposed on the quality of matching of separate elements.

The purpose of the present article is the discussion of one of the methods permitting an accurate determination of the influence of multiple internal reflections on the properties of a complex line for the transmission of UHF signals.

For the general case, such a line is represented in Fig. 1.

In this diagram, the reflection factors of different units in the network are denoted by Γ_1, Γ_2 . . . . Γ_n, and the voltage, field intensity, or power transmission factors of these units if reflection is absent, i.e., for an ideal matching of all units in the channel, are denoted by $K_{\Pi 1}$, $K_{\Pi 2}$, . . . $K_{\Pi n}$.

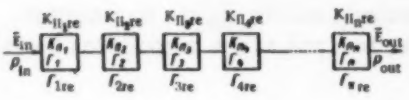


Fig. 1.

The transmission coefficients are identical to amplification factors of hot UHF devices or to attenuation coefficients of units in the cold state.

In the general case, the transmission and the reflection factors of units in the channel are not equal for the forward and the reverse directions, and, therefore, the reverse-direction factors will be further referred to by the subscript "re."

If individual units in the channel are not ideally matched, internal reflections will occur in the channel, which, depending on the character of transmission factors, can cause the intensification or attenuation of transmitted signals.

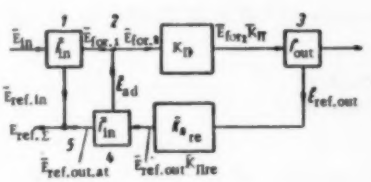


Fig. 2.

In the analysis of such complex networks, the various units of a transmission line can be characterized by an equivalent circuit (Fig. 2). In composing the circuit, it was assumed that, in its upper part, the waves are propagated only in the forward direction, and, in its lower part, only in the reverse direction. In this, the interaction of the forward and of the reflected waves was assumed to take place only in places of reflection, i.e., at the boundaries of units characterized by Γ_{in} and Γ_{out}. In the general case, the reflection factors and the transmission factors are considered to be complex quantities. The intensity of transmitted signals in various parts of the unit shown in Fig. 2 is characterized by the absolute value of the field intensity vector $\overline{E}$. The forward and the reflected waves are considered to be of the same type.

Such representation of a UHF device or of any other unit in a complex transmission line provides the possibility, in the first place, of defining the feedback arising in reflections, and, in the second place, of accurately determining the intensity and the character of feedback.

For the unit shown in Fig. 2 for a steady-state process, all changes in the intensity of transmitted signals are described by the following vector equations:

$$
\begin{aligned}
&\text{At point } 1\text{: } \overline{E}_{in} + \overline{E}_{ref\cdot in} = \overline{E}_{for\cdot 1};\\
&\text{At point } 2\text{: } \overline{E}_{for\cdot 2} = \overline{E}_{for\cdot 1} + \overline{E}_{ad};\\
&\text{At point } 3\text{: } \overline{E}_{for\cdot 2} K_n + \overline{E}_{ref\cdot out} = \overline{E}_{out};\\
&\text{At point } 4\text{: } \overline{E}_{ref\cdot out}\, K_{n\,re} + \overline{E}_{ad} = \overline{E}_{ref\cdot out\cdot at};\\
&\text{At point } 5\text{: } \overline{E}_{ref\cdot \Sigma} = \overline{E}_{ref\cdot in} + \overline{E}_{ref\cdot out\cdot at}
\end{aligned}
\qquad (1)
$$

Also, the following relations hold:

$$\begin{aligned}\bar{E}_{\text{ref·in}} &= \bar{E}_{\text{in}}\,\bar{\Gamma}_{\text{in}};\\ \bar{E}_{\text{ref·out}} &= \bar{E}_{\text{for·2}}\,\bar{K}_{\text{n}}\,\bar{\Gamma}_{\text{out}};\\ \bar{E}_{\text{ad}} &= \bar{E}_{\text{ref·out}}\,\bar{K}_{\text{n re}}\,\bar{\Gamma}_{\text{in}}\end{aligned} \tag{2}$$

Assuming that the quantities $\bar{E}_{in}$, $\bar{\Gamma}_{in}$, $\bar{\Gamma}_{out}$, $\bar{K}_{\Pi}$ and $\bar{K}_{\Pi re}$ are known, all other quantities entering (1) and (2) and, in particular, the field intensity vector $\bar{E}_{out}$ at the unit output can be easily expressed in terms of the above quantities.

From (1) and (2), it follows that

$$\bar{E}_{\text{out}} = \bar{E}_{\text{in}}\,\bar{K}_{\text{n}}\,\frac{(1+\bar{\Gamma}_{\text{in}})(1+\bar{\Gamma}_{\text{out}})}{1-\bar{K}_{\text{n}}\bar{K}_{\text{n,re}}\,\bar{\Gamma}_{\text{in}}\,\bar{\Gamma}_{\text{out}}}. \tag{3}$$

Hence, we can obtain the complex value for the $\bar{\sigma}$ factor of feedback caused by reflections:

$$\bar{\sigma} = \bar{K}_{\text{n}}\bar{K}_{\text{nre}}\,\bar{\Gamma}_{\text{in}}\,\bar{\Gamma}_{\text{out}} \tag{4}$$

This factor determines the intensity of the output signal and the operational stability of the transmission line unit under investigation in dependence on the intensity of internal reflections and on the transmission factor ratios for the direct and reverse directions.

Equations (1) and (2), written for the steady-state process in the equivalent circuit of the element shown in Fig. 2, can be easily analyzed by constructing vector diagrams.

Expressing the complex quantities by their moduli and arguments, we can write:

$$\begin{aligned}\bar{\Gamma}_{\text{in}} &= \Gamma_{\text{in}}\,e^{j\varphi_{\text{in}}}\\ \bar{\Gamma}_{\text{out}} &= \Gamma_{\text{out}}\,e^{j\varphi_{\text{out}}}\\ \bar{K}_{\text{n}} &= K_{\text{n}}e^{j\psi};\\ \bar{K}_{\text{n re}} &= K_{\text{n re}}\,e^{j\psi_{\text{re}}}\end{aligned} \tag{5}$$

For these moduli and arguments of the complex quantities, the vector diagrams corresponding to (1) and (2) are of the form shown in Fig. 3.

From the vector triangles for a given modulus E_{in} and phase shifts φ_{in}, φ_{out}, and ψ_{re}, it is easy to calculate the moduli and phases of $\bar{E}_{out}$ and $\bar{E}_{ref\Sigma}$, which are the most characteristic quantities in hot and cold measurements.

In measurements performed in the hot state, when vectors $\bar{E}_{for1}$ and $\bar{E}_{ad}$ are in phase, the actual transmission coefficient of the unit as a whole has a maximum deviation from the ideal transmission coefficient, according to which the stability in operation of this unit in a given frequency range can be evaluated.

In this case, the complex feedback factor in (3) can be replaced by its modulus, and, therefore, the amplitude of the output wave will be equal to:

$$E_{\text{out}} = \frac{E_{\text{in}}\,K_{\text{n}}\sqrt{1+\Gamma_{\text{in}}^2+2\Gamma_{\text{in}}\cos\varphi_1}\cdot\sqrt{1+\Gamma_{\text{out}}^2+2\Gamma_{\text{out}}\cos\varphi_2}}{1\pm K_{\text{n}}\,K_{\text{n re}}\,\Gamma_{\text{in}}\,\Gamma_{\text{out}}}. \tag{6}$$

and the maximum over-all transmission factor will be

$$K_{n\,\text{oa}\cdot\max} = K_n \frac{\sqrt{1+\Gamma_{in}^2+2\Gamma_{in}\cos\varphi_1}\cdot\sqrt{1+\Gamma_{out}^2+2\Gamma_{out}\cos\varphi_2}}{1-K_n K_{n\,re}\ \Gamma_{in}\Gamma_{out}}. \tag{7}$$

If the phases of these waves are in opposition, the minimum transmission factor will be equal to

$$K_{n\,\text{oa}\cdot\min} = K_n \frac{\sqrt{1+\Gamma_{in}^2+2\Gamma_{in}\cos\varphi_1}\cdot\sqrt{1+\Gamma_{out}^2+2\Gamma_{out}\cos\varphi_2}}{1+K_n K_{n\,re}\ \Gamma_{in}\Gamma_{out}}. \tag{8}$$

Thus, depending on the phase ratios of the direct and additional waves, the variation of the over-all transmission factor of the unit considered will be equal to

$$\frac{K_{n\,\text{oa}\cdot\max}}{K_{n\,\text{oa}\cdot\min}} = \frac{1+a}{1-a} = \frac{1+K_n K_{n\,re}\ \Gamma_{in}\Gamma_{out}}{1-K_n K_{n\,re}\ \Gamma_{in}\Gamma_{out}}. \tag{9}$$

Expression (9) clearly shows that the change in the over-all transmission factor and, correspondingly, the tendency to excitation, are all the greater, the greater the reflection from the unit in question and the larger the ratio of the amplification factor for the forward direction to the attenuation factor for the reverse direction.

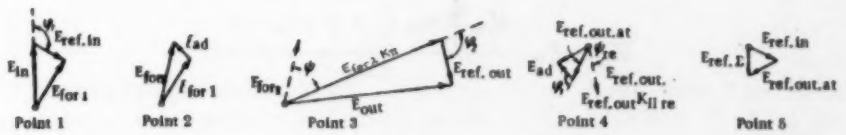


Fig. 3.

In the case where transmission systems are modified with respect to frequency, the frequency period of changes in the transmission factor of the system due to the presence of internal reflections is of great importance. For the unit under consideration, it can be readily determined from the general equations relating the phase change to the whole number of wavelengths n in a closed feedback circuit of length L:

$$\Phi_L \Delta\varphi dL = 2\pi n \text{ — for the case where the phases coincide;}$$
$$\Phi_L \Delta\varphi dL = \pi\,(2n-1) \text{ — for the case where the phases are in opposition.} \tag{10}$$

Here, $\Delta\varphi$ denotes the change of phase in section dL of the feedback circuit.

Expressions (6), (9), and (10) provide complete information on the properties of a unit in the transmission line when the direct and the additional waves are in phase due to reflections.

In measurements performed in the cold state, the most interesting case is that where vectors $\overline{E}_{ref\,in}$ and $\overline{E}_{ref\,out\,at}$ are in phase and maximum and minimum values for the modulus $E_{ref\,\Sigma}$ of the total reflected wave are obtained.

In this case, $\overline{E}_{ad}$ can be neglected and the following values of the total reflected wave amplitude can be obtained by solving the vector triangles:

$$E_{ref\cdot\Sigma\cdot\max} = E_{in}\left[\Gamma_{in}+K_n K_{n\,re}\ \Gamma_{out}\ \left(1+\Gamma_{in}^2+2\Gamma_{in}\cos\varphi_2\right)\right] = E_{in}\Gamma_{\Sigma\max};$$
$$E_{ref\cdot\Sigma\cdot\min} = E_{in}\left[\Gamma_{in}-K_n K_{n\,re}\ \Gamma_{out}\ \left(1+\Gamma_{in}^2+2\Gamma_{in}\cos\varphi_1\right)\right] = E_{in}\Gamma_{\Sigma\min}. \tag{11}$$

Hence, the following expressions for moduli Γ_{in} and Γ_{out} are obtained:

$$\Gamma_{in} = \frac{\Gamma_{\Sigma\max}+\Gamma_{\Sigma\min}}{2}; \tag{12}$$

$$\Gamma_{out} = \frac{\Gamma_{\Sigma\max}-\Gamma_{\Sigma\min}}{2K_n\ K_{n\,re}\ \left(1+\Gamma^2+2\Gamma\cos\varphi_1\right)}. \tag{13}$$

Expressions (12) and (13) provide the possibility of determining the values for Γ_{in} and Γ_{out} according to the measured values for $\Gamma_{\Sigma max}$ and $\Gamma_{\Sigma min}$. Such measurements can be easily performed, for instance, by means of double T-shaped bridges with a phase-shifting device in the measuring circuit.

For small values of Γ_{in}, when the term in brackets in (13) can be neglected, this equation assumes the form known in literature:

$$\Gamma_{out} = \frac{\Gamma_{\Sigma max} - \Gamma_{\Sigma min}}{2K_n K_{n re}} \tag{14}$$

Thus, by means of an equivalent circuit for the simplest unit in the transmission line, which is shown in Fig. 2, the process of wave propagation in such a unit can be simply and clearly represented.

The basic advantage of the method considered is the possibility of taking into account the internal reflections in more complicated networks consisting of a large number of units, as is the case of the transmission line shown in Fig. 1.

It can be easily shown that, for the case where the transmission line consists of n units, the vector of the field intensity at its output can be represented in the following form:

$$\overline{E}_{out} = \overline{E}_{in} \frac{K_{n\Sigma} \sum_{i=1}^{n} (1+\Gamma_{in\ i})\ (1+\Gamma_{out\ i})}{1-\bar{\sigma}_{\Sigma}}. \tag{15}$$

where

$$K_{n\Sigma} = K_{n1} K_{n2} \quad \ldots \ldots \ldots K_{nn}.$$

Here, (9) and (10) obtained earlier in the analysis of a single unit still hold.

Assuming that the transmission factors and the reflection factors of separate units are known, the problem of the analysis of "hot" transmission line circuits can be reduced to the analysis of the over-all feedback factor $\bar{\sigma}_{\Sigma}$. A larger number of units in the network leads to a complication of feedback circuits due to internal reflections, however, without causing difficulties in calculating σ, as it is always possible to write as many node equations as necessary for the determination of all unknown components.

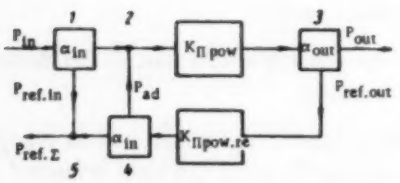


Fig. 4.

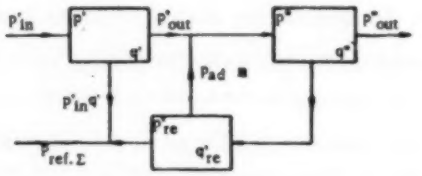


Fig. 5.

The proposed method of taking into account internal reflections permits the solution of problems of any degree of complexity by successively considering individual units in the system and then combining them into larger units. In this case, it is always possible to limit ourselves to the mathematical consideration of the simplest circuit, as shown in Fig. 2 or Fig. 4. As an example, let us analyze this problem proceeding from the circuit in Fig. 4. From there, it follows:

$$P_{out} = P_{in}\ K_{\Pi pow} \frac{\alpha_1 \alpha_2}{1 - K_{\Pi pow} K_{\Pi pow\ re} (1-\alpha_1)(1-\alpha_2)}; \tag{16}$$

$$P_{ref\ \Sigma} = P_{in} \left[1 - \alpha_1 + \frac{K_{\Pi pow} K_{\Pi pow\ re} (1-\alpha_2)\ \alpha_1^2}{1 - K_{\Pi pow} K_{\Pi pow\ re} (1-\alpha_1)(1-\alpha_2)} \right]. \tag{17}$$

Consequently, the over-all power transmission factor γ and the power reflection factor q of a unit are equal to:

$$\gamma = \frac{P_{out}}{P_{in}} = \frac{a_1 a_2 K_{n\,pow}}{1-\sigma}; \tag{18}$$

$$q = \frac{P_{ref\,\Sigma}}{P_{in}} = 1-a_1 + \frac{K_{n\,pow} K_{n\,pow\,re}(1-a_2)a_1^2}{1-\sigma}. \tag{19}$$

Here, σ denotes the feedback factor:

$$\sigma = K_{n\,pow} K_{n\,pow\,re}(1-a_1)(1-a_2). \tag{20}$$

For further calculations, it is necessary to determine the transmission and the reflection factors γ_{re} and q_{re} of the unit as a whole for the opposite direction. From an elementary analysis of the circuit in Fig. 4, it follows that:

$$\gamma_{re} = \frac{a_2 a_1}{1-\sigma} K_{n\,pow\,re} \tag{21}$$

$$q_{re} = 1-a_2 + \frac{K_{n\,pow} K_{n\,pow}\,(1-a_1)\,a_2^2}{1-\sigma}. \tag{22}$$

The obtained generalized parameters γ, γ_{re}, q, and q_{re} for the given unit can be further used in the analysis of a system consisting of two simple units. Such a system is shown in Fig. 5. Also, in this case, it is easy to obtain the following expressions from the equilibrium conditions for the steady-state process:

$$P''_{out} = P'_{in} \frac{\gamma' \gamma''}{1-q'_{re}\,q''}; \tag{23}$$

$$P_{re\ \Sigma 2} = P'_{in}\, q' \left(1 + \frac{q''\,\gamma'_{re}}{1-q'_{re}\,q''}\right). \tag{24}$$

It follows from (23) and (24) that the over-all transmission and reflection factors of a system consisting of two units are equal to:

$$\gamma_{\Sigma 2} = \frac{\gamma' \gamma''}{1-q'_{re}\,q''}; \tag{25}$$

$$q_{\Sigma 2} = q' \left(1 + \frac{q''\,\gamma'_{re}}{1-q'_{re}\,q''}\right). \tag{26}$$

By means of these generalized parameters, two of the simplest units in the system can be treated as a single unit, and, as before, investigating this one in conjunction with a third, we obtain $\gamma_{\Sigma 3}$ and $q_{\Sigma 3}$ for three elements, etc., until the whole system, no matter how complicated, has been investigated. Thereby, the calculations are prevented from becoming too complicated, which is an important advantage of this method.

The proposed method of calculation can be applied in the solution of a large number of problems.

In a following article, we shall consider its application for the separate measurement of reflection factors where the reflections are due to two and more inhomogeneities in a channel for the transmission of UHF signals.

MEASUREMENT OF THE QUALITY FACTOR OF CAVITY RESONATORS WITH SMALL DAMPING

E.I. Kulikov

Calculation formulas and analysis of measurement errors. Measurements of the quality factor of resonators with small damping where errors do not exceed ±5% are of great practical interest.

The methods of measuring the quality factor according to the resonance curve [1] and the VSWR by the slotted line [2] in the case of small damping yield errors actually exceeding ±(15-20)%.

In the method described below, the measurement of the quality factor is reduced to the measurement of the "sounding time" of a cavity resonator after it was excited by impact.

Let us consider a cavity resonator where the wall conductivity, the magnetic permeability, and the dielectric penetrance of the medium filling the volume, do not depend on the intensities of the electric and the magnetic fields.

As is known [3], the electric field strength in a resonator in free oscillations can be expressed in the following form:

$$E = E_0 e^{i\omega_0^* t}, \tag{1}$$

where

$$\omega_0^* = \omega_0 + i\frac{\omega_0}{2Q} - \tag{2}$$

is the complex frequency of natural oscillations when losses are present, and Q is the quality factor of the resonator, which is a constant quantity for the given resonator for a certain given type of oscillations.

If natural oscillations in a resonator are excited by means of high-frequency pulses, they will be damped according to the law given by (1). Obviously, the intensity of the electric field, which is governed by radiation, will also change according to the same law.

Let the resonator be connected to a crystal detector by a radiation field.

For a sufficiently small input signal, the voltampere characteristic of the detector can be considered as quadratic (in practice, the quadratic property will be preserved with great accuracy for absorbed energies less than 10^{-5} w) and then, the voltage tapped off the load of the crystal detector will be equal to:

$$U = \beta E_0^2 e^{-\frac{\omega_0 t}{Q}},$$

where β is a constant.

The voltage ratio at the output of the crystal detector at times t_1 and t_2 will be obviously expressed as:

$$\frac{U_1}{U_2} = e^{\frac{\omega_0 \tau}{Q}}, \tag{3}$$

where $\tau = t_2 - t_1$ is the time during which the voltage amplitude changes from U_1 to U_2.

From (3), we obtained the following expression for the quality factor:

$$Q = 2\pi \frac{f_0 \tau}{\ln \frac{U_1}{U_2}}. \tag{4}$$

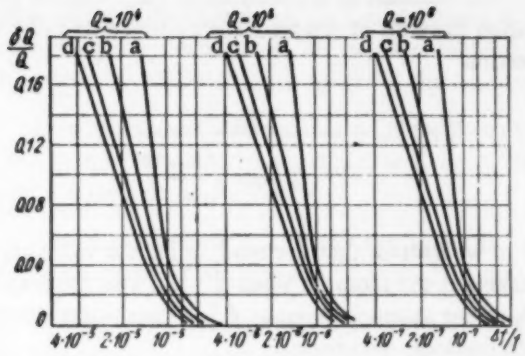


Fig. 1. $(\delta Q/Q)_{ad}$ vs. $\Delta f_0/f_0$ curve for various values of Q and $\ln(U_1/U_2)$. a) $\ln(U_1/U_2) = 1$; b) $\ln(U_1/U_2) = 2$; c) $\ln(U_1/U_2) = 3$; d) $\ln(U_1/U_2) = 4$.

Fig. 2. Block diagram of the Q-meter. 1) UHF oscillator 43-I; 2) cavity resonator; 3) detector unit with the crystal detector; 4) amplifier 103-I; 5) oscillograph 25-I.

Frequency, Mc	Quality factor	
	by visual method	by photographic method
9300	87000	86500
9330	87300	87000
9350	94400	95500

The maximum relative error in measuring Q is determined by the following expression after simple transformations:

$$\frac{\delta Q}{Q} = \frac{\delta f_0}{f_0} + \frac{\delta \tau}{\tau} + \frac{1}{\ln \frac{U_1}{U_2}} \cdot \frac{U_2}{U_1}\,\delta\left(\frac{U_1}{U_2}\right), \quad (5)$$

where δf_0, $\delta \tau$, and $\delta(U_1/U_2)$ are the errors in determining the frequency, time, and the voltage ratio.

For $U_1/U_2 = e \approx 2.7183$, Eqs. (4) and (5) become simpler and assume the form:

$$Q = 2\pi f_0 \tau, \quad (6)$$

$$\frac{\delta Q}{Q} = \frac{\delta f_0}{f_0} + \frac{\delta \tau}{\tau} + \frac{1}{2{,}72}\,\delta\left(\frac{U_1}{U_2}\right). \quad (7)$$

For $U_1/U_2 = e^2 = 7.3891$

$$Q = \pi f_0 \tau, \quad (8)$$

$$\frac{\delta Q}{Q} = \frac{\delta f_0}{f_0} + \frac{\delta \tau}{\tau} + \frac{1}{14{,}8}\,\delta\left(\frac{U_1}{U_2}\right). \quad (9)$$

As can be seen from (5), (7), and (9), the basic errors in measuring the quality factor of cavity resonators are connected with the measurement of the time τ and the voltage ratio U_1/U_2, as the relative error in frequency measurements is, as a rule, less than 0.01%.

The direct measurement of τ and U_1/U_2 from the curve on the screen of a modern oscillograph, by means of a scale grid and calibration marks, yields a total error of the order of ±5%.

Due to the instability of the frequency of excitation oscillations, the determination of the quality factor according to (4), (6), and (8), by measuring U_1/U_2 and τ by the visual method using an oscillograph, will yield additional errors due to the blurring of the curve on the screen (this error can be eliminated by using single sweeps in photographing the oscillogram of the oscillation damping process and the time mark).

Let us evaluate the error caused by these circumstances.

In the general case, for small disturbances, the amplitude of the electric field intensity will be determined by the expression [3]:

$$E_0^* = \frac{i\omega I_0}{\omega^2 - \omega_0^{*2}}, \quad (10)$$

where ω is the frequency of oscillations to be excited; ω_0^* is the complex resonance frequency of a cavity resonator, determined from (2); I_0 is a quantity proportional to the amplitude of the excitation current.

Substituting (2) in (10), and considering that $Q \gg 1$ and $\omega - \omega_0 = \Delta\omega_0$, where $\omega \approx \omega_0$, we have:

$$E_0^* = \frac{II_0}{2\Delta\omega_0 - i\frac{\omega_0}{Q}}. \quad (11)$$

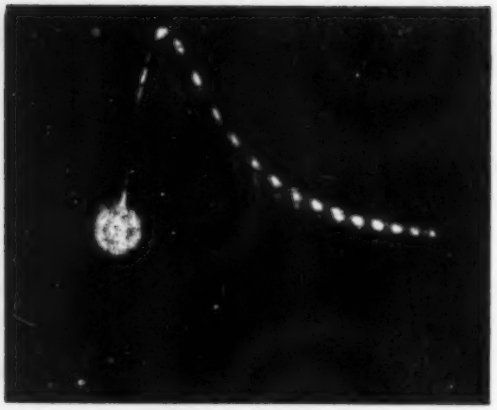


Fig. 3. Influence of frequency stability on the damping curve shape (the duration of calibration marks was 0.5 μsec).

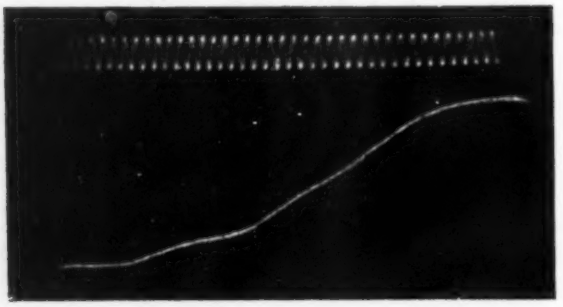


Fig. 4. Damping and oscillation curves for the 5 Mc frequency.

The modulus of the amplitude $|E_0^*|$ will be determined in terms of the resonance amplitude E_0 by the expression

$$|E_0^*| = \frac{E_0}{\sqrt{1+4Q^2\left(\frac{\Delta\omega_0}{\omega_0}\right)^2}}.$$

If we assume that the reading for the value U_1 was taken at the moment when $\omega = \omega_0$, and the reading for U_2 at the moment when $\omega \neq \omega_0$, then, after simple transformations, we obtain:

$$\frac{U_1}{U_2} = \left[1+4Q^2\left(\frac{\Delta f_0}{f}\right)^2\right] e^{\frac{2\pi f_0 \tau}{Q}}.$$

Hence, we find:

$$\tau_1 = \frac{Q}{2\pi f_0}\left\{\ln\frac{U_1}{U_2} - \ln\left[1+4Q^2\left(\frac{\Delta f_0}{f_0}\right)^2\right]\right\}.$$

For the ideal case, we find from (3):

$$\tau_2 = \frac{Q}{2\pi f_0}\ln\frac{U_1}{U_2}.$$

Then, the relative additional error in calculating Q according to (4), (6), and (8) will be equal to

$$\left(\frac{\delta Q}{Q}\right)_{add} = \frac{\delta\tau}{\tau} = \frac{\ln\left[1+4Q^2\left(\frac{\Delta f_0}{f_0}\right)^2\right]}{\ln\frac{U_1}{U_2}}. \quad (12)$$

Figure 1 shows the $(\delta Q/Q)_{ad}$ vs. $\Delta f_0/f_0$ curves. It can be seen from the curves and Eq. (12) that, in order to make sure that the additional error in measuring Q, which is due to the frequency instability of excited vibrations, does not exceed 2% during the measurements, we should have a UHF vibration source with a frequency stability equal to [for $\ln(U_1/U_2) = 2$]:

$$\frac{\Delta f_0}{f_0} < \frac{1}{10Q}.$$

EXPERIMENTAL

A device, the block diagram of which is shown in Fig. 2, was constructed in order to test this method of measuring the quality factor of cavity resonators with a high Q-factor.

An electromagnetic energy pulse of a duration of 1 μsec, supplied by the 43-I standard signal generator, excited a cylindrical cavity resonator from a 50-I instrument with $H_{01,\,18}$ waves. A part of the electromagnetic energy from the cavity resonator was transmitted to the detector unit through a communicating opening. The signal from the crystal detector output was fed, after amplification in a broadband 103-I amplifier, to the 25-I oscillograph which was operating in slave sweeps lasting 2 μsec.

The measurement of time during which the amplitude changed five-fold was performed with respect to the calibration marks of the 25-I oscillograph in the following manner: the input attenuator of the oscillograph (calibrated beforehand) was adjusted for "1:5" and the position of the curve under investigation was marked ac-

cording to the reference notch on the oscillograph screen; then, the input attenuator was adjusted for "1:1," and the scanning was shifted until the curve coincided with the reference mark; the shift of scanning was measured with respect to the calibration marks of the oscillograph.

Due to an insufficient stability of the frequency of oscillations excited during the measurement process (in the case where the UHF oscillator was not sufficiently warm), the damping curve for the cavity resonator assumed the form shown in Fig. 3.

The measurement of time during which the amplitude changed fivefold was performed with respect to the upper contour of the curve by means of calibration marks with an accuracy of ±5%.

Beside visual measurements of the quality factor on the oscillograph screen, the damping curve for oscillations in a cavity resonator and for oscillations of a frequency of 5 Mc excited by a 100-I oscillator was photographed on the screen of the OK-17M double-trace oscillograph by means of single slave sweeps. The 5 Mc frequency was preliminarily checked with the 526 heterodyne wavemeter.

The shape of the damping curve and of the 5 Mc frequency curve are shown in Fig. 4 (the accuracy of measurements on the photograph is equal to ±3%).

The table shows the results of measuring the quality factor of the cavity resonator of a 50-I instrument by the visual method and by the method of photographing at different frequencies.

The above accuracy in measurements of the quality factor of cavity resonators by the visual method can be considerably increased in comparison with the accuracy obtained (5%) by using calibrated voltage dividers and sanatron circuits for the measurement of τ [5].

LITERATURE CITED

[1] R.A. Valitov and V.N. Sretenskii, Radio Measurements at Super-High Frequencies [in Russian] (Voenizdat USSR, 1951).

[2] V.I. Yuzvinskii, "On measuring the quality factor of cavity resonators," Trudy of the NII, ONTI 20, 3 (1956).

[3] A.G. Gurevich, Cavity Resonators and Waveguides [in Russian] ("Soviet Radio" Press, 1952).

[4] Crystal Detectors [Russian translation from English] ed. by E.Ya. Pumper ("Soviet Radio" Press, 1950) Vol. 1.

[5] Tube Circuits for Time Measurements [Russian translation from English] ed. by A.Ya. Breitbart ("Soviet Radio" Press, 1951) Vol. 1.

THE LOCATION OF AVERAGE VELOCITY ON THE VERTICAL FREE WATER FLOW

G.V. Zheleznyakov

In connection with the preparation of standards for the measurement of water flow in river beds and open channels by the area-velocity method, which are being prepared by the ISO/TK 30 (Subcommittee 1) and the All-Union Scientific-Research Institute of the Committee of Standards, Measures, and Measuring Instruments, the present article considers the problem of the location of average velocity on the vertical free water flow. The determination of the coordinate of a point on the velocity vertical at which the local velocity $\underline{u}$ is equal to the average velocity u_v on the vertical is of practical importance in two basic cases: for small working depths of the velocity vertical – approximately from 0.10 to 0.35 m [1], and also where it is necessary to speed up the hydrometric operations, for instance, if the water flow is unsteady.

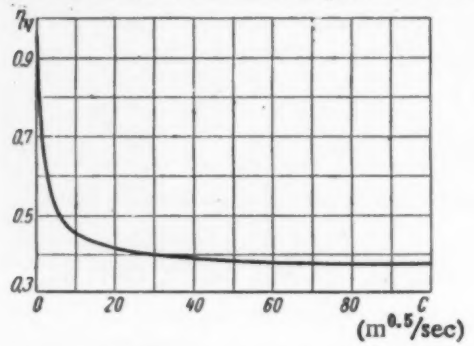


Fig. 1. Dependence of the relative ordinate η_v on the velocity factor C.

In [1], it was assumed that, for free turbulent flow, u_v is located at a constant relative distance $\eta_v = 0.4$ from the bottom of the flow.

A generalization of data on the velocity distribution along the vertical provides the possibility of solving this problem with greater accuracy.

We shall proceed from the exponential equation for the velocity distribution along the vertical [2]:

$$\frac{u}{u_{max}} = \eta^{\frac{1}{m}}, \tag{1}$$

where u_{max} is the maximum (surface) velocity on the vertical; $\eta = y/h$ is the relative depth; $\underline{y}$ is the distance from the bottom of the flow; $\underline{h}$ is the flow depth on the vertical.

From (1), we find the expression for the average velocity on the vertical

$$u_v = \frac{1}{h}\int_0^h u\,dy = \frac{m}{1+m}\,u_{max}. \tag{2}$$

Taking into account (1) and (2), we find:

$$\frac{u}{u_v} = \left(\frac{1+m}{m}\right)\eta^{\frac{1}{m}}. \tag{3}$$

If $u = u_v$, then $\eta = \eta_v$, and, consequently:

$$\left(\frac{1+m}{m}\right)\eta_v^{\frac{1}{m}} = 1. \tag{4}$$

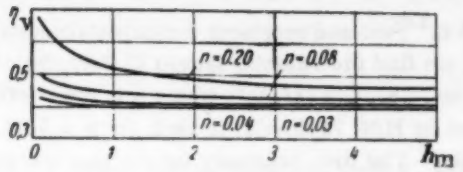


Fig. 2. Dependence of the relative ordinate η_v on the depth h of the velocity vertical and the roughness coefficient n of the bottom.

TABLE 1

Values of C $m^{0.5}$/sec for $\eta_v = 0.40$	$\Delta\eta_v$ %		
	1.0	2.0	3.0
C_{min}	25	19	15
C_{max}	48	70	~100
$C_{max}-C_{min}$	23	51	~85

TABLE 2

h_m \ n	0.03	0.04	0.08	0.20
0.10	0.42	0.45	0.50	0.67
0.14	0.42	0.44	0.49	0.65
0.18	0.42	0.44	0.48	0.63
0.22	0.41	0.43	0.48	0.62
0.28	0.41	0.43	0.47	0.60
0.40	0.41	0.42	0.46	0.58
0.60	0.40	0.42	0.45	0.55
0.80	0.40	0.41	0.44	0.53
1.00	0.40	0.41	0.44	0.52
1.50	0.40	0.40	0.44	0.50
2.00	0.39	0.40	0.43	0.48
2.50	0.39	0.40	0.42	0.47
3.00	0.39	0.40	0.42	0.46
4.00	0.39	0.40	0.42	0.46
5.00	0.39	0.40	0.42	0.45

whence

$$\eta_v = \left(\frac{m}{1+m}\right)^m . \qquad (5)$$

The expression for the exponent m is found from the equation derived in [2, 3]:

$$m = \frac{\kappa C}{\sqrt{g}}, \qquad (6)$$

where k is the flow parameter; C is the velocity factor in the equation for steady flow [4]; g is the acceleration due to gravity.

The parameter k has been considered as a universal constant for a long time. In our investigations of free flow [2], we proved that k is not a universal constant. This conclusion was confirmed in the study of water flow in pipes [5] At the present time, the value 0.54, which we obtained in experimental work on flow in rivers, is used as the average value of k in investigations of free flow. A figure very close to this value for k (0.55) was obtained in investigations of velocity-distribution curves for large channels [6].

Later, the derived Eq. (6) was also published in [7]. Equation (6) can be expressed in the following form:

$$m = \frac{\kappa\sqrt{2}}{\sqrt{\lambda}}, \qquad (7)$$

as $C = \sqrt{2g}/\sqrt{\lambda}$, where λ is the friction coefficient reduced to the hydraulic radius.

As (6) agrees well enough with experimental data [6, 8], we are justified in applying it in the determination of the location of average velocity on the vertical in free flow.

Substituting (6) in (5), for k = 0.54, we obtain:

$$\eta_v = \left(\frac{0.172\ C}{1+0.172\ C}\right)^{0.172\ C} . \qquad (8)$$

The graph of this function is shown in Fig. 1.

The smaller C, the higher the distance from the flow bottom of the point where $u = u_v$. According to Fig. 1, we can establish for what range of C can the value $\eta_v = 0.40$ be accepted in dependence on the allowance $\Delta\eta_v$ for the accuracy in placing the instrument (a hydrometer, a hydrometric tube, etc.) at the point in question. The corresponding numerical data are given in Table 1.

Thus, the rule, which is accepted in all countries, of measuring the average velocity on the vertical by means of the so-called single-point method where the point is located at the distance $\eta_v = 0.4$ from the bottom (0.6 from the surface), is valid for a certain given range of velocity factors C. Strictly speaking, the quantity η_v

is variable and should be determined according to (8) or the graph in Fig. 1. For $C < 25\ m^{0.5}/sec$, the deviation of η_v from the value 0.4 is most noticeable.

Let us consider in more detail the values of η_v for $C < 25\ m^{0.5}/sec$ and represent the calculation data for η_v in the form convenient for use in practice. For this purpose, we find the velocity factors C from the equation derived by N.N. Pavlovskii, which is applied for the given vertical, i.e., $C = (1/n)h^y$, where n is the coefficient of roughness. For $n \leq 0.04$ [4], the value of the exponent y given by N.N. Pavlovskii is used, for $n > 0.04$, the value provided in the norms of the Glavgidroénergostroi [9] is used. The data necessary for plotting the graph of the function $\eta_v = \eta_v(n,h)$ in Fig. 2 were obtained by calculations based on (8). With an increase in roughness (n) and a decrease of depth (h), η_v increases. This is expressed by the following equation:

$$\eta_v = \left(\frac{0.172\ h^y}{n+0.172\ h^y}\right)^{\frac{0.172}{n}} h^y, \tag{9}$$

which is obtained by substituting N.N. Pavlovskii's expression for C in (8).

It is obvious from Fig. 2 that, for $n = 0.08$ (corresponding to river beds), $\eta_v > 0.4$. For very rough river beds ($n = 0.20$) and small depths h, the values for η_v differ even more from the norm values for η_v. Still not enough attention is paid to the measurement of water flow over bottom land. Thus, for certain given values of η_v, depending on the hydraulic conditions of flow, it is possible to improve the method of measuring free water flow, particularly the flow in river beds. In practice, it is convenient to use a table giving the values for η_v (see Table 2) in dependence on n and h (where the values for η_v are rounded off to 0.01).

With respect to pressurized flow, the dependence of η_v on roughness has not been derived [10], as, in experiments with pipes, the range of roughness variation is considerably smaller than that in rivers and channels.

SUMMARY

1. The relative coordinate η_v of the point (measuring from the bottom) where the local velocity is equal to the average velocity on the vertical in free turbulent flow decreases with an increase of the velocity factor C, which corresponds to an increase in η_v with an increase in roughness and a decrease in depth; this is expressed by (8) and (9).

2. The directions provided in the norms for the use of the single-point method of measuring the average velocity on the vertical for $\eta_v = 0.40$ are valid if $C > 25\ m^{0.5}/sec$. For $C < 25\ m^{0.5}/sec$, it is recommended that η_v be determined according to Table 2 in dependence on n and h.

3. If we accept an allowance of $\Delta\eta_v = 1\%$ for the placing of the instrument at the point in question, the problem arises of using variable values of η_v also for large values of C ($C > 48\ m^{0.5}/sec$); this problem can be solved by means of (8) and the graph in Fig. 1.

LITERATURE CITED

[1] Instructions for Hydrometeorologic Stations and Observation Posts No. 6, Part I (Gidrometeoizdat, 1957).

[2] G.V. Zheleznyakov, Izv. AN SSSR, Technical Sciences Section 8, 1947.

[3] G.V. Zheleznyakov, Hydraulic Principles of Methods Used in River Hydrometry [in Russian] (AN SSSR Press, 1957).

[4] A.N. Akhutin and G.V. Zheleznyakov, Hydraulics [in Russian] (VIA Press, 1951).

[5] F.A. Shevelev, Investigation of Basic Hydraulic Laws of Turbulent Flow in Pipes [in Russian] (Gosstroizdat, 1953).

[6] U.O. Rodionov, Dopovidi (Doklady) Akad. Nauk Ukrainian SSR 4, 1954.

[7] S.A. Obrazovskii, Trudy of the Hydraulic Laboratory of the VODGEO 4, 1955.

[8] I.K. Nikitin, Trudy of the SANIIRI 91, 1958.

[9] M.F. Sribnyi, Coll.: Calculation of Stream Deflecting Works in Bridge Constructions [in Russian] (Transzheldorizdat, 1937).

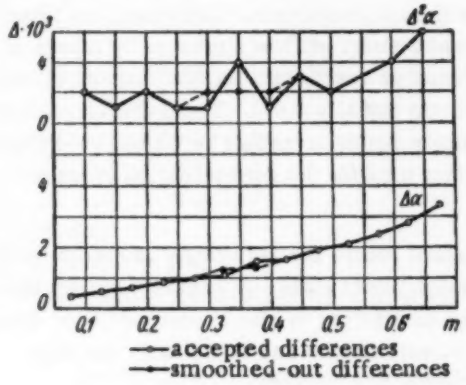
[10] A.D. Al'tshul', Izmeritel'naya Tekhnika 3, 1956.

DISCHARGE COEFFICIENTS OF DIAPHRAGMS AND NOZZLES

S.S. Kivilis

The present article considers some results of our investigations of discharge coefficients of flow-contraction devices.

Discharge coefficient of diaphragms with a modulus* of 0.35. Let us analyze the initial discharge coefficients of diaphragms set forth in German standards [1] and in Regulations 27-54 [2], for which we shall compose a diagonal table of finite differences of the function** $\alpha = f(m)$; we shall assume that the increment of values in the table is constant and equal to 0.05 (Table 1). Hereafter, we shall denote a finite difference of the n-th order by the symbol Δ^n.



As can be seen from Table 1, the differences in the upper and lower parts of the table vary quite evenly (the existing insignificant discontinuities can be explained by errors due to rounding off the values for α), while in the middle part of the table, sharp changes in differences can be observed.

As the function under consideration is continuous and rising, such a distribution of differences as shown in Table 1 is possible when all table values of the function are valid except one [3]. In this case, the differences of an even order with the largest absolute values of errors are in the same horizontal line resulting from the erroneous value of the function, and the odd differences with the largest absolute values of errors are immediately above this line or under it. Hence, it can be concluded that, in our case, the value $\alpha = 0.645$, which corresponds to the modulus 0.35, is inaccurate.

TABLE 1

Modulus m	Discharge coefficient [1,2]	$\Delta\alpha \cdot 10^3$	$\Delta^2\alpha \cdot 10^3$	$\Delta^3\alpha \cdot 10^3$
0.05	0.598	4		
0.1	0.602		2	
0.15	0.608	6		−1
0.2	0.615	7	1	1
0.25	0.624	9	2	−1
0.3	0.634	10	1	0 (1)
0.35	0.645 (0.646)	11 (12)	1 (2)	3 (0)
0.4	0.660	15 (14)	4 (2)	−3 (0)
0.45	0.676	16	1 (2)	2 (1)
0.5	0.695	19	3	−1
0.55	0.716	21	2	1
0.6	0.740	24	3	1
0.65	0.768	28	4	2
0.7	0.802	34	6	

Note. Figures in brackets represent the corrected values of the discharge coefficient and of finite differences.

Applying Scarborough's method [3], it can easily be established that, if the values for α are accurate for all other moduli, the value for α corresponding to the modulus 0.35 must be equal to 0.646.

*Hereafter, the modulus of a flow-contraction device is defined by $m = d^2/D^2$.

**In order to simplify the notation, the initial discharge coefficient will be denoted by α (instead of by α_u).

The corrected values of discharge coefficients and differences are shown in brackets in Table 1. Obviously, we obtained smoother transitions of difference values; the first and second differences change smoothly enough, and the third differences are practically constant.

The necessity for correcting the values of α for the 0.35 modulus is also convincingly illustrated by graphs for differences of the first and second orders for equal intervals of the argument (see figure).

Additional confirmation of the value of $\alpha = 0.646$ for the 0.35 modulus is provided by the results of approximately the function $\alpha = f(m)$ by polynomials, which was performed by the author (see below for further details). Taking the values for α corresponding to moduli 0.1, 0.2, 0.3, 0.4, etc. as the initial points, we obtain the value of $\alpha = 0.646$ for the intermediate 0.35 modulus in both variants of the solution, which are considered below.

Interpolation formulas for discharge coefficients. As is known, the functional dependence of the discharge coefficient on the contracting piece modulus has not been established in analytical form. Therefore, the international recommendations as well as the national standards for the measurement of flow discharge by means of flow-contraction devices provide only discrete values of the initial discharge coefficient for rounded-off values of the modulus, which are arranged in table form with a certain increment (usually 0.05). These discharge coefficient values for any shape of flow-contraction devices serve as reference points according to which, by different methods, interpolation tables or graphs are constructed, which are further used for the determination of intermediate values of the discharge coefficient.

In principle, it is perfectly obvious that such a table or graph cannot secure the uniformity of results in determining the coefficients, particularly if the tables are used on an international scale. In connection with this, it is convenient to approximate the empirical function of the discharge coefficient vs. the modulus of flow-contraction devices by an analytical expression which would permit a relatively simple and sufficiently accurate calculation of the discharge coefficient for different moduli of flow-contraction devices.

Since, according to the first Weierstrass theorem, any continuous function can be replaced by a polynomial, we shall use ordinary polynomials of the form

$$P(x) = \sum_{k=0}^{n} a_k x^k \tag{1}$$

with real coefficients [4].

Operations with such polynomials are very convenient as they are the simplest functions.

By applying a quadratic approximation, the problem can be formulated in the following manner: we have to find a polynomial $P(x)$ of the $n < S$ degree (where S is the number of given discrete values of the function), which, at the given points, assumes such values that the sum of squares of deviations from the given function values is a minimum.

Thus, taking the discharge coefficients of diaphragms corresponding to the moduli for the initial values, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, and 0.7, it is possible, as shown by calculations, to obtain a sufficiently good approximation of the function $\alpha = f(m)$, which is given in discrete form, by means of the 4th-degree polynomial

$$\alpha = 0.5962 + 0.0157\ m + 0.4633\ m^2 - 0.4734\ m^3 + 0.5420\ m^4. \tag{2}$$

In calculating the coefficients of polynomial (2), the values of arguments of initial points (moduli) were chosen with an increment of 0.1 in order to be able to judge the quality of the performed approximation according to the values of the function calculated for a modulus increment of 0.05.

The values of the discharge coefficient of diaphragms with a modulus from 0.05 to 0.7 (for increments of 0.05), calculated according to Eq. (2) with four decimal places,* are given in Table 2 in the column "Variant I" where the deviation of these values from those accepted in standards are also indicated.** We see that (2) represents a satisfactory empirical functional dependence of the discharge coefficient on the diaphragm modulus (the maximum deviations from experimental values do not exceed 0.13%).

*Four decimal places are necessary in order to secure a gradual change of finite differences.

**For the 0.35 modulus, the corrected value for α is indicated.

TABLE 2

Modulus m	Accepted values of α [1,2]	Calculated values of α								Proposed values for α
		variant I (one polynomial)		variant II (three polynomials)						
		α from (2)	$\lvert\delta\alpha\rvert$ %	α from (5)	$\lvert\delta\alpha\rvert$ %	α from (6)	$\lvert\delta\alpha\rvert$ %	α from (7)	$\lvert\delta\alpha\rvert$ %	
0,05	0,598	$0,598_1$	0,015	$0,597_8$	0,03	—	—	—	—	$0,597_8$
0,1	0,602	$0,602_0$	0	$0,602_0$	0	—	—	—	—	$0,602_0$
0,15	0,608	$0,607_6$	0,07	$0,607_8$	0,03	—	—	—	—	$0,607_8$
0,2	0,615	$0,615_0$	0	$0,615_0$	0	—	—	—	—	$0,615_0$
0,25	0,624	$0,623_8$	0,03	$0,623_8$	0,03	$0,624_4$	0,07	—	—	$0,623_8$
0,3	0,634	$0,634_2$	0,03	$0,634_0$	0	$0,634_0$	0	—	—	$0,634_0$
0,35	0,646*	$0,646_3$	0,05	$0,645_8$	0,03	$0,645_9$	0,015	—	—	$0,645_9$
0,4	0,660	$0,660_2$	0,03	—	—	$0,660_0$	0	—	—	$0,660_0$
0,45	0,676	$0,676_2$	0,03	—	—	$0,676_4$	0,06	$0,675_9$	0,015	$0,676_4$
0,5	0,695	$0,694_6$	0,06	—	—	$0,695_0$	0	$0,695_1$	0,015	$0,695_0$
0,55	0,716	$0,715_8$	0,03	—	—	$0,715_9$	0,015	$0,716_0$	0	$0,716_0$
0,6	0,740	$0,740_4$	0,05	—	—	—	—	$0,739_8$	0,03	$0,739_8$
0,65	0,768	$0,768_9$	0,13	—	—	—	—	$0,767_9$	0,012	$0,767_9$
0,7	0,802	$0,801_9$	0,012	—	—	—	—	$0,801_9$	0,012	$0,801_9$
0,75	0,843**	—	—	—	—	—	—	$0,843_0$	0	$0,843_0$
0,8	0,892**	—	—	—	—	—	—	$0,892_5$	0,06	$0,892_5$

Remarks:

*Corrected value.

**Calculated according to experimental data by Vitte [5].

In a similar manner, we can obtain a function relating the modulus and the discharge coefficient of nozzles, which is of the form:

$$\alpha = 0.9899 - 0.0992\ m + 1.0181\ m^2 - 1.8473\ m^3 + 1.8776\ m^4. \tag{3}$$

The maximum deviation from experimental data of the values for α calculated according to (3) also does not exceed 0.13%.

However, it should be noted that the obtained equations are not entirely suitable for the composition of interpolation tables of discharge coefficient values, as they do not secure the required accuracy. By further increasing the degree of polynomials, the calculations by interpolation would be made more cumbersome, and, therefore, for greater accuracy, it is convenient to perform the approximation not by one, but by several lower-degree polynomials, each corresponding to a limited interval of the modulus values. This problem can be solved by methods of interpolation of functions and can be formulated in the following manner [4].

Let $y = f(x)$ be a uniform function of the independent variable x, which is continuous in a given interval and assumes the values $y_0, y_1, y_2, \ldots y_n$ at points $x_0, x_1, x_2, \ldots x_n$ in this interval. We have to find a polynomial $P(x)$ of the n-th degree, which, at $n + 1$ given points (interpolation nodes), assumes the same values as the given function $f(x)$ and represents exactly or approximately this function at other points in the interval where

$$|f(x) - P(x)| < \varepsilon,$$

where ϵ is the maximum allowable error characterizing the quality of the approximation of $f(x)$ by $P(x)$.

In the case of an empirical function given in discrete form, the above inequality can be satisfied at any point in the interval by a suitable choice of the independent variable increment (in performing the experiments).

In order to obtain the polynomials in question, proceeding from equidistant interpolation points $x = a + kh$ ($h \neq 0$; $k = 0, 1, \ldots n$), we shall use Newton's interpolation polynomial which, in its general form, is written thus [5]:

$$P(x) = \sum_{k=0}^{n} \frac{\Delta^k f(a)}{k!\, h^k} A_k(x), \tag{4}$$

where $\Delta^k f(a)$ are finite differences of the order $\underline{k}$ (k = 0, 1, . . . n);

$$A_k(x) = \prod_{k=1}^{n} (x - a - \overline{k-1}h), \text{ whereupon } A_0(x) \equiv 1.$$

As in the case of approximation by one polynomial, we shall take the values of the flow-contraction device modulus with increments of 0.1 as interpolation nodes, so that the accuracy of the polynomial could be evaluated according to the given discharge coefficients for the intermediate values of moduli, which differ from the interpolation points by 0.05.

For each polynomial, it is convenient to select the intervals of moduli in such a manner that the values of interpolation functions almost coincide in a certain interval, i.e., so that a smooth transition from one function to another is achieved.

Diaphragms. Let us divide the entire interval of moduli from 0.05 to 0.8 into three sections: 1) 0.05-0.3; 2) 0.25-0.5, and 3) 0.45-0.8. The interpolation nodes 0.1, 0.2, and 0.3 can be conveniently selected for the first section, and the points 0.3, 0.4, and 0.5 and 0.45, 0.55, 0.65, and 0.75, for the second and third sections, respectively.

TABLE 3

	m	α	$\Delta\alpha \cdot 10^3$	$\Delta^2\alpha \cdot 10^3$	$\Delta^3\alpha \cdot 10^3$
1st section	0.1	0.602	13	6	—
	0.2	0.615	19		
	0.3	0.634			
2nd section	0.3	0.634	26	9	—
	0.4	0.660	35		
	0.5	0.695			
3rd section	0.45	0.676	40	12	11
	0.55	0.716	52	23	
	0.65	0.768	75		
	0.75	0.843			

The values of the interpolation function that correspond to these points, and the finite differences of the function are given in Table 3. Applying Newton's interpolation polynomials for each interval of moduli, we shall obtain the following interpolation functions:

$$\alpha = 0.595_0 + 0.04\,m + 0.3\,m^2, \tag{5}$$

$$\alpha = 0.610_0 - 0.055\,m + 0.45\,m^2, \tag{6}$$

$$\alpha = 0.349_5 + 1.4454\,m - 2.4249\,m^2 + 1.8333\,m^3. \tag{7}$$

The values of the discharge coefficient calculated according to (5), (6), and (7) are given in Table 2 in the column "Variant II."

Obviously, the function (5) can be conveniently used for moduli $m \leq 0.3$, the function (6) for $0.3 < m \leq 0.5$, and function (7) for $m > 0.5$. The thereby obtained "smoothed-out" values for the discharge coefficient are given in the last column of Table 2; the largest discrepancy between the "smoothed out" values and those provided in standards is equal to 0.6%.

Nozzles. Dividing the 0.05-0.65 interval of moduli into two sections (0.05-0.4 and 0.35-0.65) and taking moduli 0.1, 0.2, 0.3, 0.4, and 0.35, and 0.45, 0.55, and 0.65 as interpolation nodes for these intervals, respectively, we obtain the following interpolation functions:

$$\alpha = 0.987_0 - 0.02\,m + 0.4\,m^2 \tag{8}$$

and

$$\alpha = 0.910_0 + 0.6258\,m - 1.4\,m^2 + 1.6667\,m^3. \tag{9}$$

The nozzle-discharge coefficient values, calculated according to (8) and (9), are given in Table 4.* Obviously, the equations obtained represent a very good approximation of the given function; the first should be used for $m \leq 0.4$, and the second for $m > 0.4$. The thereby obtained "smoothed-out" discharge coefficient values for rounded-off modulus values with 0.05 increments are given in the last column of Table 4; the largest of the discrepancies between these values and the accepted values is equal to 0.05%.

TABLE 4

Modulus, m	Accepted values of α [1,2]	Calc. values of α for nozzles: α from (8)	|δα| %	α from (9)	|δα| %	Proposed values of α
0.05	0.987	0.987_0	0	—	—	0.987_0
0.1	0.989	0.989_0	0	—	—	0.989_0
0.15	0.993	0.993_0	0	—	—	0.993_0
0.2	0.999	0.999_0	0	—	—	0.999_0
0.25	1.007	1.007_0	0	—	—	1.007_0
0.3	1.017	1.017_0	0	—	—	1.017_0
0.35	1.029	1.029_0	0	1.029_0	0	1.029_0
0.4	1.043	1.043_0	0	1.043_0	0	1.043_0
0.45	1.060	—	—	1.060_0	0	1.060_0
0.5	1.081	—	—	1.081_2	0.02	1.081_2
0.55	1.108	—	—	1.108_0	0	1.108_0
0.6	1.142	—	—	1.141_5	0.05	1.141_5
0.65	1.183	—	—	1.183_0	0	1.183_0

SUMMARY

1. The table of initial discharge coefficients of diaphragms should be corrected by taking the coefficient value 0.646 (instead of 0.645) for the 0.35 modulus.

2. The functional dependence of the initial discharge coefficient on the modulus of flow-contraction devices, represented by a polynomial of the 4th degree, yields deviations from the accepted values not exceeding 0.13%.

3. In order to compose interpolation tables, it is convenient to approximate the function $\alpha = f(m)$ for diaphragms by three polynomials, and that for nozzles by two polynomials, each corresponding to a certain given interval of moduli. The error in such approximation does not exceed 0.06% for diaphragms, and 0.05% for nozzles. The use of these equations secures uniform results in the interpolation of coefficients.

LITERATURE CITED

[1] DIN 1952, VDI – Durchflussmessregeln, VI (Ausgabe, 1948).

[2] Instructions 27-54 for the Use and Checking of Flow Meters with Standard Diaphragms, Nozzles, and Venturi Tubes [in Russian] (Mashgiz, 1955).

[3] J. Scarborough, Numerical Methods of Mathematical Analysis [in Russian] (Gostekhizdat, 1934).

[4] V.L. Goncharov, Theory of Interpolation and Approximation of Functions [in Russian] (Gostekhizdat, 1954).

[5] Antrage der deutschen Delegation zur Sitzung des ISA – Komitees 30 in Helsinki, 1939.

*As in Table 2, the coefficients are given with four decimal places in order to smooth out the finite differences.

ESSAYS AND REVIEWS

MEASURING INSTRUMENTS AT THE TWELFTH EXHIBITION OF CHEMICAL INSTRUMENTATION "AKHEMA 1958"

E.N. Belikov

The Twelfth Exhibition of Chemical Instrumentation "Akhema 1958" was held in Frankfurt-on-Main (FGR) from May to June 1958.

The present survey provides a short description and the characteristics of the most interesting exhibits in the field of instrumentation – electrical measurement devices and electric devices for the measurement and recording of various nonelectric quantities.

Electrical measurements. The Dr. B. Lange firm developed a photoelectric two-coordinate self-recorder for the registration of functions of the form $y = f(x)$ with ink on ordinary millimeter paper. The device contains a self-recorder "Model 2" with a recorder drum and a motor drive for the pen. The motion of the pen in the direction of the ordinate is controlled by the light beam of a "Multiflex" galvanometer and the motion in the direction of the abscissa is controlled by the light beam of another galvanometer, which passes through a photoelectric adapter. The adapter contains a transistor amplifier which actuates the motor, the spindle of which carries the photocell. The system operates in such a way that the photocell follows a shifting light beam. The adapter is connected through a coupling to the axle of the recording drum of the self-recorder. Any type of the "Multiflex" galvanometer can serve as the first galvanometer. Instead of the second galvanometer, a light beam reflected from a mechanically moving mirror can be used for controlling the pen motion in the direction of the abscissa. The instrument permits the registration of currents of $5 \cdot 10^{-11}$ amp and voltages of $5 \cdot 10^{-7}$ v.

The compensation amplifier of low dc voltages produced by the Goettinger Messtechnik Firm is based on the Lindek-Rote principle and can be used in conjunction with an indicating instrument or with a self-recorder. The measurement ranges are: 5, 7.5, and 10 mv. The output current is proportional to the input voltage with an accuracy of $\pm 0.2\%$. The nominal load resistance at the instrument output is equal to 3 kohm. For averaging out the quantity measured by means of the amplifier, a device with a time lag constant adjustable from 0 to 20 sec is provided. The error in measuring the average value is equal to 0.5%.

The P. Firkhov Nakhfgr firm exhibited a compensation system for the remote measurement of various quantities which are transformed into electric current and voltage. The measurement method is based on the compensation of two moments of rotation, one of which is proportional to the quantity to be measured, and the other to the compensating current. The compensating moment of rotation changes automatically until it becomes equal to the moment of rotation created by the quantity to be measured, so that the compensating current is proportional to the quantity in question. Depending on the quantity to be measured, a magnetoelectric measuring mechanism or the Ferraris mechanism can be used in the system. A diaphragm placed between an illuminator lamp and the photocell is mounted on the axle of the measuring system which is acted upon by the two mentioned moments of rotation. As the diaphragm moves, the illumination of the photocell changes, and the photocell controls, through an electron amplifier, the compensating current which is measured by an indicating instrument. The transformed quantities can be transmitted to a distance of 30 km. Steady readings are established in 0.3 to 1 sec, depending on the converter type used for the conversion of quantities to be measured.

Electrical measurements of nonelectric quantities. Instruments for the measurement of mechanical forces and vibrations. Induction converters QI, produced by the Goettinger Messtechnik Firm, permit the measurement of tensile forces of 0.5 to 10 g. In conjunction with the KWS II/5 measuring amplifier (for a carrier frequency

of 5 kc), forces equal to 0.025 g can be indicated. Other variants of converters have measurement ranges of 5-100 g, 5-1000 g, and 500-10,000 g. Depending on modification, the range of natural frequencies of the converters is 150-3000 cps, which permits the performance of not only static, but also dynamic measurements at frequencies over 100 cps. The displacement of the measuring element does not exceed 0.05 mm, so that the point of force application can be considered as practically fixed.

The Siemens and Gal'ske firm developed magnetostriction converters for the measurement of forces of several hundreds of tons, which are not sensitive to vibrations and have small over-all dimensions. The converters consist of specimens made of ferromagnetic material, on which inductance coils are fixed. As mechanical stresses act on the specimen, the impedance of inductance coils changes due to a variation in magnetic permeability. The impedance is measured by means of a differential circuit and can be registered by a self-recorder. The converter can be used for governing a signalling device and can be also applied in control circuits. The change in impedance is so great that usually no additional amplification is necessary.

For geophysical investigations of vibrations, the Goettinger Technik Firm developed a V4 vibration converter. The natural frequency of the data transmitter for vertical oscillations is equal to 1 cps, and that of the data transmitter for horizontal vibrations 2.4 cps. A 100,000-fold amplification can be secured in conjunction with a KWS II/5 amplifier. The measurement range is from ± 0.001 to ± 1 mm and the threshold of sensitivity is $5 \cdot 10^{-5}$ mm.

Instruments for pressure and flow measurements. The majority of exhibits at the Exhibition have been already demonstrated in previous years at exhibitions in Hanover and Duesseldorf.*

From among the new instruments, flow meters compensated with respect to pressure and temperature of the medium measured and also converters for the conversion of electrical dc and ac quantities into pneumatic signals should be noted.

The converter produced by the Taylor Instrument Companies of Rochester has an electric input and pneumatic outputs. The amplifier input current (from 0 to 5 ma) is transformed by a built-in electropneumatic converter into pneumatic signals of 0.2 to 1 kg/cm^2. Additional dc instruments can be connected to the device. Power supply voltage variations of $\pm 10\%$ cause errors less than $\pm 0.5\%$ of the output signal range. The lower measurement limit is 3 mv or 6 ohm. The zero of the instrument can be suppressed within -10 to $+40$ mv.

For the measurement of pressure of liquids and gases, the Goettinger Messtechnik Firm developed P-2h converters whose measurement ranges are 0-500 kg/cm^2, which permits the performance of highly accurate static and dynamic measurements at high frequencies. The measuring element is a hollow cylinder provided with wire SR-4 gauges, which are connected to a bridge circuit. The pressure causes elastic deformation of the cylinder, and the balance of the bridge is disturbed.

The output voltage of the bridge in a dc circuit is measured by means of a potentiometer, and in an ac circuit, by means of a measuring amplifier. In measuring dynamic processes, the maximum frequency is mainly determined by the elasticity of the medium measured, as the natural frequency of the converter is approximately equal to 20 kc. The built-in compensation and correction elements guarantee a measurement error less than $\pm 0.5\%$ of the measurement range. The gauges are compensated for temperature changes in the range from -10 to $+45$°C.

Instruments for temperature measurements. The Siemens and Gal'ske Company exhibited several models of radiation pyrometers for the measurement of temperatures in the interval from -40 to $+1750$°C. The pyrometer of the "Ardometer" model (steady readings established in 2.1 sec) with a quartz lens is designed for the measurement of temperatures from $+400$ to $+1200$°C, and the pyrometer with a glass lens, for temperatures from $+700$ to $+1750$°C. By means of the "Ardonoks" pyrometer (with a tubular mirror), temperatures from $+600$ to -40°C can be measured (steady readings established in 2-3 sec). The model "Ardofot" with a measurement range from $+500$ to $+1350$°C has been developed for the measurement of quick temperature changes (0.001 sec). A germanium photodiode serves as the radiation receiver. The influence of temperature on the photocurrent, which distorts the measurement results, is eliminated by a compensation measuring circuit. The photodiodes almost do not age and the maximum of their spectral sensitivity lies in the ultrared region for a wavelength of 1.5 μ.

*See "Izmeritel'naya Tekhnika," 1, 85, 1956; Information Bulletins of the VNIIK No. 0-9, 0-34, and 0-56; "Priborostroenie," 12, 24, 1958.

The automatic electronic potentiometer developed by the Goettinger Messtechnik Firm with a round scale 220 mm in diameter has a switching mechanism with six scales mounted on the front panel, whereby various regulating devices covering the entire measurement range can be connected. The reading error of the instrument is 0.5%, and that of a custom-built instrument 0.25%; the error in establishing the contacts is equal to 0.1%. The times required for the indicator hand to sweep over the entire scale are 1.2 and 5 sec.

The new miniature thermocouples with external diameters of 0.5 to 1 mm, which are produced by the Phillips Company, are characterized by high sensitivity to small temperature changes. Four types of thermocouples are produced for the measurement of temperatures from −200 to +1000°C. The thermocouples are designed mainly for use in devices for multipoint control and in high-pressure apparatuses.

pH-meters. The PR 9400 instrument, produced by the Phillips Company, is suitable for any kind of pH measurements, for potentiometric titration, and also for the measurement of electrostatic charges. The dc voltage on the electrodes is transformed into alternating voltage by means of a dynamic capacitor and is then amplified and rectified. The system is encompassed by negative dc voltage feedback. A magnetoelectric instrument with a scale graduated in pH units or in millivolts, is connected to the feedback circuit. The input circuit, the dynamic capacitor, and the power and the output transformers are enclosed in a dust- and moisture-proof casing. The measurement ranges are: 0-6 pH, 3-9 pH, 8-14 pH, and 0-1200 mv. The sensitivity threshold is 0.01 pH or 2 mv. The reproductiveness and the reading errors are equal to 0.01 pH or 2 mv. The maximum measurement error is 0.02 pH or 10 mv.

A portable instrument (model PR 9401) with a dry cell for direct readings, produced by the same firm, is suitable for almost any kind of pH measurements. The constant electrode voltage is amplified by an electrometric amplifier encompassed by deep negative feedback. A magnetoelectric device with a scale graduated in units of pH is connected to the feedback circuit. The measurement range is 2-12 pH. The sensitivity threshold is less than 0.02 pH, and the reproductiveness and reading errors are 0.02 pH. The instrument is temperature-compensated in the interval from 0 to +100°C.

The PR 9402 model pH-meter has the same electric circuit as the universal PR 9400 model, but is constructed in the shape of a panel instrument. The instrument has a low-resistance output.

If the pH data transmitters operate for a long time in polluted sewage waters and solutions with colloidal components, a deposit is formed on the electrodes, which causes errors in measurements. The Siemens and Gal'ske Company developed a device for the automatic cleaning of electrodes. A brush driven by a motor periodically cleans the surface of the glass electrode, touching it only during a period of 15 sec in order to reduce wear.

An amplifier with a vibrapack, which is encompassed by deep negative feedback, is used in the industrial pH-meter produced by the Siemens and Gal'ske Company. A positive feedback is also provided in the amplifier for the partial charging of the capacitor connected before the vibrapack by the amplifier output voltage. The presence of two feedback circuits secured an amplifier input resistance of more than 10^{11} ohm. The amplifier is built into a moisture-proof cast housing where additional devices for the adjustment of readings by means of buffer solutions and devices for amplifier calibration are mounted.

A model K electronic device produced by the Bekkmen Instrument Company, is designed for the measurement and regulation of pH and for automatic titration. For titration, an electromagnetic valve is provided, which, after admitting 95% of the titration liquid, actuates a device which limits the feed and guarantees an accurate termination of the process. Four burets can be controlled by means of this instrument. The measurement range is 0-14 pH. The errors do not exceed 0.05 pH or 5 mv.

Instruments for continuous gas analysis. The Model 220 gas chromatograph, manufactured by the Bekkmen Company, is designed for the continuous control of gas and smoke concentration in plants. Normally, the instrument registers only the assigned gas components, but it can also register a complete chromatogram. When several media are analyzed, additional devices for taking samples are connected to the instrument. The self-recorder can be placed at a distance of 500 m from the chromatograph. The instrument can also be used for the control of complex mixtures of saturated, unsaturated, or aromatic hydrocarbons.

The technical characteristics of the instrument are: the interval of operating temperatures of the column is from +40 to +110°C, and the error in maintaining a steady temperature ±0.1°C; the temperature interval of the working volume is from −30 to +45°C; the minimum rate of flow of the gas sample is equal to 3 liter/hour;

the minimum pressure of the gas sample is 75 mm Hg; the measurement range is from 1 to 100%; the measurement errors are equal to 0.5-2% of the measurement range.

Instruments for humidity measurements. The Phillips Company developed the PP2200H automatic double measuring bridge for the measurement and recording of relative humidity. The instrument takes into account the functional relation between the dew point and temperature. The PP6000H humidity detector is connected to one of the bridge circuits, and the temperature detector PP6001H is connected to the other bridge. The bridges are interconnected in such a manner that the resulting output voltage of the measuring circuit is proportional to relative humidity. The measurement of this voltage is performed by the compensation method by means of a phase-sensitive automatic device.

The Brabender Company exhibited a device for the continuous control and recording of humidity of friable materials, for instance, coal, sawdust, chemical by-products, and other materials, which are transported by conveyers. The instrument measures the frequency change of high-frequency vibrations propagated through the product under inspection, which is caused by a change in the dielectric constant of the material when its humidity content varies. Temperature compensation is provided in order to eliminate measurement errors due to fluctuations of the surrounding temperature. The instability of the generated frequency, which is equal to 13.56 Mc, is less than 0.1%.

An instrument developed by the Consolidated Electrodynamics Corporation is designed for the continuous measurement of the humidity content in gases of as little as 10^{-4}% by volume. As the gas under investigation passes through the instrument, the humidity in the gas is continuously absorbed and electrolyzed. The current necessary for electrolysis serves as the measure of the humidity content.

In writing this survey, material from the following journals published in 1958 was used: "Elektronische Rundschau," "Regelungstechnik," "ETZ-A," "BWK," and others.

INFORMATION

PROBLEMS IN MEASUREMENT AUTOMATION DISCUSSED AT THE INTERCOLLEGIATE SCIENTIFIC CONFERENCE

The Intercollegiate Scientific Conference where the contemporary state and the prospects for the development of instrumentation were considered, was held from April 21 to April 23, 1959 in Moscow. About 150 scientists, engineers, and technicians from Moscow, Leningrad, Kiev, and other cities took part in the work of the section "Instruments and Automatic Devices for Dimension Control." Twenty-two reports by representatives from colleges, scientific-research institutes, and other organizations were heard and discussed.

Specialists from abroad: Prof. K.N. Kyubler, Doctor-Eng. Lippert, Eng. Ekkeryunst (GDR), and Eng. Bobovich (PPR) also presented their reports to the Conference.

The preservation of the uniformity of measures is of special importance in the standardization of parts in machine construction and, especially, in the automatization of industrial processes, specialization and wide cooperation.

In his report on the present state of the problem of a length standard, G.D. Burdun (of the Moscow Institute of Machine Tools) expressed the opinion that the existing platiniridium meter prototype cannot satisfy the requirements of modern metrology, as it reproduces the unit of length with an accuracy not greater than 0.1-0.2 μ. At the same time, interference-type measurements of length standards provide the possibility of attaining an accuracy of a few hundredths of a micron.

The development of interference measurement methods and the progress of physical sciences permit the establishment of a unique length standard in meter form, expressed by the length of light waves.

At the Eleventh General Conference on Measures and Weights, which will be held in 1960, the International Committee of Measures and Weights will present the project of a resolution proposing that a meter be defined as a length equal to 1650763.73 wavelengths in radiation vacuum corresponding to the transition between the $2P_{10}$ and $5d_5$ levels in an atom of crypton 86, and that the definition of the meter, which has been in force since 1889 and is based on the international platiniridium standard, be declared invalid.

At the present time, the Geneva Physics Society for Measures and Weights is preparing for the International Bureau of Measures and Weights an interference photoelectric comparator for direct measurements of accurate standard scales and length standards in terms of lengths of light waves.

By the use of this comparator and by changing over to the standard emission of light of the crypton 86 isotope, the accuracy of linear standard measurements will increase up to 100-fold.

The report by S.S. Volosov (of the Moscow Institute of Machine Tools) was devoted to the technological aspect of accuracy of active methods in the inspection of dimension parameters.

The accuracy of machining is determined by many physicotechnical and technological factors. They include errors directly caused by physical phenomena in the process of shaping; errors in machining caused by inaccuracy in the manufacture of tools; errors in the adjustment of machine tools; machining errors connected with elastic deformations of the production system (machine tool–work–instrument–adapter) under the influence of temperature and force factors; errors due to wear of equipment and instruments, etc.

The production control devices do not eliminate these errors, but they provide the possibility of controlling the manufacturing process in such a way that the accuracy of the product is within certain given limits.

The speaker considered the existing methods of production control, including the feedback variants used in these methods, the errors of these control methods, and the possibilities of reducing them.

The report by I.A. Vul'fson of (ÉNIMS) discussed the present state and the prospects for developing measuring systems for machine tools with digital programming control.

The speaker related that, at the present time, our industry achieved a certain success in the development of machine tools with digital control. For instance, three new models of machine tools – two milling machines and one lathe – have been designed and manufactured in ÉNIMS. These systems are relatively simple and they are based on the application of more reliable elements.

A number of other organizations also achieved positive results in this direction.

The speaker discussed the existing systems for the movement control of working parts of machine tools – the relay and the continuous control systems.

In the first case, at the moment when the signal indicating that the required motion has been completed is received, the signal for stopping the table is given. In order to secure the required accuracy, the system reduces the speed immediately before stopping.

Step systems, which, in many cases, can be more efficient than systems with ordinary motors, represent variants of the relay-type system.

Continuous-tracking systems can theoretically secure a great accuracy. However, in practice, such following is justified only in systems with very high operational accuracy.

The following most typical systems of indicating devices for feedback data transmitters were considered in the report.

1. Systems for machine tools of medium accuracy, based on the application of force-transmitting screws used as measuring screws. A data transmitter signalling the completion of the required motion is connected to the screw. These systems are simple, but they are not very accurate,as the screws wear out and are subject to deformation in transmitting the motion.

The step systems are provided mainly in the form where force-transmitting screws are used for measurement.

2. Systems where, along with power screws or other forms of drive, separate measurement screws are used.

3. Systems where magnetic or optical scales are used, whereby the movement of the working part is directly measured. The use of pulse counters is typical for these systems.

4. Systems where progressive motion is transformed into rotary motion by means of rotating transformers, selsyns, etc.

For motion-control systems of a relatively low accuracy – of 0.05 mm – for a scale division of the same order, systems with step motors are recommended; for systems with an accuracy of 0.01 mm, the use of inductive data transmitters and for systems of higher accuracy, the use of optical data transmitters is recommended.

In order to secure a widespread use of feedback data transmitters, it is necessary to speed up the solution of technological problems.

The reports by V.S. Vikhman of (NIÉL VPTI), A.T. Draudin (of the Bureau of Standardization of the Committee of Standards, Measures and Measuring Instruments), representatives of OKB of the Moscow Council of National Economy I.N. Khaskin and A.Ya. Peliks, analyzed the present state and the possibilities of the development of automatic control devices.

A large number of reports were devoted to the discussion of the present state and the possibilities for the development of special measuring instruments.

The reports by V.A. Egorov (of VNIIK), Yu.V. Kolomiitsov (of GOI), and Yu.N. Lyandon (of the Bauman MVTU), analyzed the present state and the prospects for the development of instruments for the control of surface roughness, distortion of shape, and other errors, characterizing the surface quality of parts, and also of devices and methods for the control of these instruments and of means for increasing their accuracy.

Noteworthy are the IZK-40 and IZK-56 interferometers, developed by V.P. Linnik (of GOI), which secure a direct and very accurate control of the surface profile of parts over a great length according to the distortion of interference bands; also the IZK-58 interferometer permitting the measurement with an accuracy of 0.03-0.1 μ

of spot deviations (for instance, waviness) of the surface of balls 2-11 mm in diameter from the ideal spherical shape. The IZK-40, IZK-56, and IZK-58 interferometers and the microinterferometers developed by V.P. Linnik won the Grand-Prix at the World's Fair in Brussels.

The macroprofile tracer for the continuous control of shape inaccuracies of transverse and longitudinal cross sections of parts, which has been developed in the Bauman MVTU, is of great interest.

In his report, N.N. Markov (of the Bureau of Standardization of the Committee of Standards, Measures, and Measuring Instruments) described new instruments and proposals for the improvement of methods and devices for the control of gears, including proposals forwarded by the Standardization Bureau, TsNIITMASH, and other organizations.

The report by A.K. Kutai and L.I. Bolonkina was devoted to original autocollimation instruments for measuring the angle pitch of worm gears, grooves, Maltese crosses, and other parts developed by the Leningrad Institute of Cinematography Engineers.

The report by B.I. Druzhinin and B.I. Isaev analyzed new single-measurement and multimeasurement instruments for the inspection of the following bucket parameters: the bucket profile (nondestructive inspection), the longitudinal cross-section angle of buckets, the ridge thickness and the edge thickness, the displacement of the bucket profile and of the longitudinal cross-section angle, and the shifting of the lock axis with respect to the working profile.

Some instruments are universal and can be used in the control of similar parameters of not only different buckets but also of other parts.

Such instruments include a copying tracer intended for the reproduction of complicated profiles of parts (internal as well as external) on a transparent motion-picture film. This instrument provides the possibility of successively tracing the external and internal profiles of buckets in order to determine the shift of one profile with respect to the other by means of a special device fastened to the tracer rod. The fastening of the part (bucket) under inspection is achieved by a special device whereby the part is fixed in the control position.

The report by N.I. Novikov (of TsNIITMASH) considered new methods and control devices for the inspection of large-size parts, including the measurement method by means of an arc goniometer which has been developed by the author.

The report by G.I. Shilov (LITMO) was devoted to instruments for the automatic inspection of thickness of coatings in mass production, including the TPO-1 instrument for thickness measurements of nonmagnetic coatings on a ferromagnetic base layer. This device permits, beside the visual observation by means of a needle indicator, the separation of good parts, the rejection of parts faulty with respect to the lower (tolerance) limit, and the rejection of parts faulty with respect to the upper tolerance limit.

The report by I.D. Fainerman (of the Kiev Polytechnical Institute) presented an analysis of inaccuracies of measuring instrument scales and recommendations for the reduction of these errors.

The report by V.V. Golovinskii (of the Ordzhonikidze MIEI) on the present state of statistical methods of control in the USSR and abroad was also heard and discussed at the conference. The speaker presented a detailed analysis of the positive experience gained in the application of these methods in the USSR and abroad and indicated ways for their further development.

The participants at the conference noted that the application of the theory of probability and mathematical statistics in technology and production control, in conjunction with methods of progressive technology and automation, can provide a substantial help in the following directions:

in the improvement of technological processes, accuracy, and efficiency by means of periodic analyses of statistical process characteristics, detection, and elimination of defects in production, systematic calculations and accuracy analysis in manufacturing basic machine parts, and the development of standardized, typical, and grouped technological processes based on these procedures;

in organizing a modern and efficient acceptance control of finished products, in the analysis of forms of defects and reasons for their appearance, and in improving the production quality by means of introducing optimum selections;

in the development of systems for the active control of equipment and technological processes on a statistical basis with the aim of securing the most efficient adjustment of automatized technological processes;

in the statistical analysis of operating characteristics of machines, machine tools and instruments, in order to secure a further improvement of reliability, lifetime, and efficiency in the operation of these implements;

in statistical processing of data obtained by investigation, laboratory and plant testing, inspection, etc.;

in the determination of tolerances compatible with efficiency in measuring circuits, etc.;

in the analysis of methods for improving the efficiency of processes and the efficiency of workers and inspectors;

in the work of Communist Labor teams and of skilled-labor teams, and also in evaluating improvements in production quality.

A.Ya.

FROM THE NATIONAL COMMITTEE OF THE USSR FOR AUTOMATIC CONTROL

The Academy of Sciences of the USSR established the National Committee of the USSR for Automatic Control, which is, on the recommendation of the International Federation of Automatic Control (IFAC), holding its First International Congress in Moscow from June 25 to July 5, 1960.*

At the present time, the International Committee of the USSR is studying the received notes outlining the reports to be presented at the Congress. The reports (notes) pertain to basic problems in modern theory and also to devices for automatic regulation and control and the application of automation in industry. A considerable number of notes submitted to the National Committee are devoted to problems in the automatization of measurements and measurement techniques in industry.

The number of notes received exceeds by a wide margin the number of reports which can be presented at the Congress. The authors whose papers passed the preliminary selection were required to submit reports which will have to pass the final selection before they are included in the program of the Congress.

The selection of reports should be completed by October,1959. By this time, the Committee will decide on the question of publishing in scientificotechnical journals certain reports which were not included among those to be read at the Congress.

*See "Izmeritel'naya Tekhnika" 6, 11, 1958.

BOOK REVIEWS

A.V. Ervais, ADJUSTMENT AND REPAIR OF OPTICOMECHANICAL MEASURING INSTRUMENTS, Mashgiz, Moscow, 1958, 458 pp., 237 illus., 8000 copies

L.N. Timoshenko

The book reviewed here consists of ten chapters. Chapter I contains brief information on optics, necessary for the mechanic who adjusts the optical instruments in measuring the dimensional parameters of products. This chapter also describes the basic types of optical parts used in measuring instruments.

Chapter II provides general instructions with respect to adjustment and repair of instruments; instruments and devices for checking opticomechanical instruments are also given.

The six following chapters (III, IV, V, VI, VII, and VIII) are devoted to the adjustment and repair of optical indicators, optical-length meters, tool- and universal microscopes, projection measuring instruments, and optical dividers.

These chapters, all of which are composed in the same manner, contain descriptions of various instrument designs, the sequence in dismantling the main parts, and methods of eliminating the defects. Beside instruments produced by domestic industry, these chapters provide a description of designs of instruments manufactured by some foreign companies.

Chapter IX describes the methods of adjustment and repair of the most common components of opticomechanical instruments; high-center heads, flat glass stages, adapters for inside measurements, double-image ocular heads, and different kinds of measurement knives and measuring end-pieces.

Chapter X is devoted to repair operations in the reconditioning of measuring instruments. Included are the methods of cleaning the optical parts and practical instructions for the preparation of scales and grids, reconditioning of mirrors and other optical parts, preparation of glass screens and glass slides, and surface-finishing of metallic parts.

The book contains a systematic list of operations necessary for the adjustment of opticomechanical instruments which are most widely used in metal machining industry. However, the book does not include such instruments as the length-measuring machine and the contact interferometer, which are often used in industry.

The arrangement of the material pertaining to the cleaning of optical parts of instruments is also one of the shortcomings of the book.

In connection with the fact that the adjustment of instruments is almost always accompanied by a complete or partial cleaning of optical parts, the instructions for cleaning should have been incorporated in each chapter concerning the adjustment of instruments. These chapters should have contained a description of methods used in the preparation of scales or grids (mechanical, photographic, and other methods) and the location of scales and grids (upper or lower surface) should have been indicated along with instructions for cleaning them. These instructions are very important as the scales or grids can be easily damaged during the process of cleaning and the instrument is thereby rendered unserviceable.

Instructions for the cleaning of optical parts are given in the chapter "Repair Operations in the Reconditioning of Measuring Instruments," however, the above-mentioned items are not treated, and the instructions are not convenient for use, as the instructions for cleaning an instrument of a certain type have to be found in the general section.

The criterion for determining which of the parts must be cleaned should also have been indicated. For instance, if the field of view in the optical indicator tube is soiled, the tube does not necessarily have to be taken completely apart and all its optical components cleaned. It is sufficient to turn the ocular or to shift the measuring rod in order to determine which part has to be cleaned. The absence of such instructions can make such a time-consuming operation as the cleaning of optical parts considerably more difficult.

It was hardly necessary to burden a book devoted to practical instructions for the adjustment of instruments with calculations of maximum measurement errors, especially since the calculations are given only for optical indicators and length meters. It would have been sufficient to indicate the maximum measurement errors for a certain instrument, as was done for all other instruments in the book.

Data guaranteed by the Zeiss Firm are given in the table of maximum measurement errors for the tool microscope model produced by domestic industry. If the errors of domestically produced microscopes do not exceed the indicated errors, these data should have been quoted without referring to the Zeiss Company.

The departure from the commonly accepted designations and terms in the text should also be noted. Thus, the length standard is referred to in the book as a plate, setting measure, special plane-parallel measure, checking plate, etc. The maximum measurement error of the instrument is called the total error, total maximum error, maximum error of the measurement method, maximum magnitude of error, etc.

The book contains a reference to the OST NKTM 20126-39 standard which was revoked in 1956.

Regardless of certain shortcomings, the book reviewed here is a valuable practical manual for adjusters, as it contains all the necessary information for the adjustment of opticomechanical instruments which are most widely used in industry. The book will be very useful for workers in branches of departmental control and in repair and adjustment services.

MATERIAL RECEIVED BY THE EDITORIAL BOARD

AN AUTOMATIC DEVICE FOR THE PREVENTION OF OVERLOADING OF OSCILLOGRAPH VIBRATORS IN TENSOMETRIC MEASUREMENTS

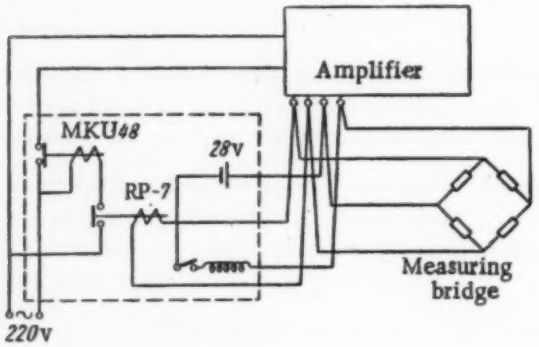
G.E. Dukhovnyi

In tensometric measurements of dynamic processes by means of oscillographs, the vibrators can be damaged by overloads if the gauge is destroyed or its current supply interrupted.

An automatic device which cuts off the voltage from the amplifier feeding the vibrator in 0.04 sec has been developed in UFNII.

The automatic device (see figure) consists of two relays (MKU-48 and RP-7 or RP-4), a switch, a dry cell, and a choke whose inductance is 0.3-0.5 h.

A 2.8 v dc voltage is fed to the feed diagonal of the tensometric bridge circuit through a switch and a choke. The choke is provided in order to make the operation of the ac tensometric circuit independent of the mentioned additional dc circuit. The winding of a RP-7 or RP-4 dc relay, which have a large inductive reactance, and, therefore, do not affect the normal operating conditions, is connected in parallel to the measuring bridge diagonal.



If one arm of the bridge is broken, a dc voltage appears in the measuring diagonal. Thereby, the RP-7 relay operates and closes the circuit feeding the MKU-48 relay. The latter operates and breaks the normally closed contacts provided in the feed circuit of the amplifier rectifier.

In order to prevent the winding of the output transformer of the ac generator and the winding of the amplifier input transformer from influencing the operation of the automatic device, the dc and ac circuits are broken by means of capacitors.

The time necessary for reducing the vibrator voltage to a safe magnitude (after the bridge arm has been broken) for a type I vibrator, is equal to 0.04 sec, and for type V and VIII vibrators, 0.9-0.13 sec. An overload of such duration cannot damage the vibrators.

For the protection of several vibrators operating at the same time, only one RP-7 relay and one 0.3-0.5 h choke are added for each vibrator.

In order to reduce the duration of overloads in the vibrator to the actual vibrator operation time – 0.04 sec – it is sufficient to use one of the pairs of the normally closed contacts of the MKU-48 relay in order to break the amplifier feed circuit by means of the anode voltage.

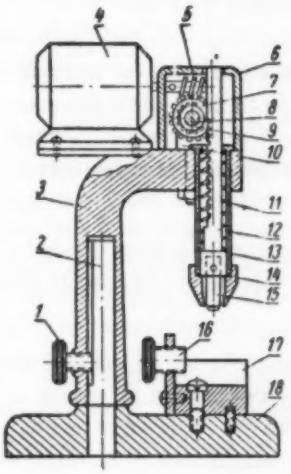
MECHANIZATION OF THE STAMPING OF WEIGHTS

A.S. Poroshin

A device for mechanizing the stamping of weights which has been designed by the author, is under construction in the Mitin foundry plant of the Tula Council of National Economy. The diagram of the device is shown in the figure.

A plate 18 serves as the base of the machine where a prism 17 with an adjusting screw 16 is fixed. A stand 2, along which the vertical column 3 moves, is pressed into the plate. A sleeve 13, containing rack 12 and spring 11, is fastened in the column head.

At its reinforced end, the rack is provided with a socket for the stamp. The rack and the spring are kept inside the sleeve by means of nut 14.



An axle 8, carrying gears 7 and 9, where gear 9 is stripped of one-fifth of its teeth, is mounted in the bearings of supports 10 which are fastened in the column head.

An electric motor 4 with a worm gear 5 mounted on its shaft is fastened to a platform on the column.

The gears and the worm gear are covered by housing 6.

The machine is operated in the following manner.

The weight is placed on block 17 with its handle facing upward. By turning the adjusting screw 16, the handle of the weight is bo ught in line with the stamp. When the tightening screw 1 is loosened, column 3 is freed and can be lowered until the stamp comes into contact with the weight. Then, while lowering the column, the rack 12 is pulled out of housing 6 to a distance equal to the pitch of the rack teeth, and the column is fixed by the tightening screw 1.

The machine is activated by pressing the starter button. The electric motor 4 drives the axle 8 by worm-gear transmission, and gear 9, which meshes with the teeth of rack 12, lifts the rack together with stamp 15. At the same time, spring 11 is compressed.

As the meshing of gear 9 with rack 12 is interrupted, the latter is forced downward by spring action. As a result, the stamp hits the weight handle and a mark is left on it.

As the next cycle of meshing between gear 9 and rack 12 starts, the stamped weight is taken off block 17 and another weight of the same nominal mass is put in its place. The lateral alignment of the weight handle with the stamp is done with respect to the lower end of nut 14.

The output of the machine depends on the speed with which the rack moves and the time necessary for placing and removing the weights from the block.

An experimental model of the machine which was manufactured by the author was driven by an ac 50-w turning motor at 1490 rpm, and its output was equal to 1000 weights per hour.

A SIMPLIFIED METHOD OF CHECKING TRUCK SCALES

I.T. Dzyuman

The checking of truck scales by means of ballast loads if standard weights amounting to 1000 kg are available, by the method prescribed by the Committee Instructions 15-52, causes considerable waste of time and manual labor.

Moreover, it is difficult to find weights amounting to 9 t on state and collective farms, especially on threshing grounds in the steppes where truck scales are extensively used.

The calibration of truck scales by using standard weights amounting to 2500 kg and trucks has been extensively practiced in the Lugansk GKL since 1957, which reduced to 2-3-fold the time required for calibration, increased the accuracy, and eliminated the necessity for providing different kinds of weights.

At the present time, each farm provided with truck scales has, as a rule, a GAZ-51 truck and GKL and the scale repair stations are provided with several tons of standard weights of 20 kg.

Obviously, under such conditions, it is not difficult to transport 2500 kg of weights in a GAZ-51 truck to the place where the calibration is to be performed, but, in this case, the weight applied to the wheels must not be less than 50% of the maximum load of 10-ton truck scales (the weight of the GAZ-51 truck is equal to 2710 kg); by means of this weight, the scales are checked for the accuracy of readings, and discrepancies are determined by approaching the scales from each side.

In case 5-5.5-t or 7.5-8-t trucks are not available, or in the case of breakdowns, etc., the truck is loaded with earth and its weight is brought up to approximately 5 t; then, by adding weights, the scales are readily calibrated for weights up to 7500 kg.

The calibration is performed in the following manner: after the scales are checked for 0.1 of the full load, we verify the accuracy of the location of notches on the balance arm and the accuracy of readings by means of standard weights up to the notch corresponding to a weight of 2500 kg. Having recorded the scale error at the given notch, we take the weights off the platform, and, without removing the balance weight from the notch, we take the GAZ-51 truck by using the rider on the secondary scale.

After that, standard weights corresponding to each notch up to a load of 5000 kg are gradually added on the platform, the accuracy of the location of notches is checked, and the scale error is determined as the rider is moved to the 5000 kg notch. The error will be equal to the algebraic sum of errors detected at the 2500 and the 5000 kg notches.

Afterward, the calibration is performed by means of the mobile load on trucks weighing 5000 or 7500 kg and by means of available standard weights amounting to 2500 kg, where the error will be determined, as in the first case, according to the algebraic sum of errors at the initial and the final notch of the section calibrated.

In calibrating 25,000-kg scales, we apply a similar procedure and use two trucks, placing them on the platform of the A-25 (b) scales.

RECORDING OF RESULTS OF STATE INSPECTION OF MEASURES AND MEASURING INSTRUMENTS

A.I. Suvorov

In many cases, the stamping by impact methods causes the deformation of individual parts of instruments (balance arms of scales, beakers, fillers for grain scales, and others, and also of technical class II weights of small denominations).

At the same time, the progress of chemical industry in the production of chemicals, durable lacquer paints, and adhesive coatings provides the possibility of dispensing with obsolete methods of stamping.

However, modern methods of marking glass surfaces replacing the use of ammonium fluoride which is harmful to persons handling it are still very little used in inspection practice.

For a considerable number of measures and instruments which are widely used (for instance, the universal measuring instrument), the control results are recorded on a standard certificate, which is time consuming and overburdens the enterprises with a large number of documents which become out of date after a short time.

Small-size forms of the simplest composition should be developed for such measures and instruments.

The ways and methods of recording the results of state inspection of measures and measuring instruments, which have been set forth in instructions and directions issued by the Committee of Standards, Measures and Measuring Instruments, should be revised. The recording of state inspection results for those instruments which are provided with a serial number and a certificate should be limited only to a check mark on the certificate, the checking date, the signature of the state inspector, and the rubber stamp. Other measures and instruments should be marked by special chemically stable adhesive paints.

The question of marking instruments by special revision marks by means of rubber stamps when revisions are carried out simultaneously with actual inspection should also be considered.

COMMITTEE ON STANDARDS, MEASURES, AND MEASURING INSTRUMENTS

FROM THE COUNCIL OF EXPERTS OF THE COMMITTEE

N.I. Evstyushin

In 1958, the Council of Experts of the Committee of Standards, Measures, and Measuring Instruments at the Council of Ministers of the USSR took into consideration a number of scientific research works performed in the D.I. Mendeleev All-Union Scientific-Research Institute of Metrology (VNIIM), the All-Union Scientific-Research Institute of the Committee of Standards, Measures, and Measuring Instruments (VNIIK), the All-Union Scientific-Research Institute of Physicotechnical and Electronic Measurements (VNIIFTRI), the Kharkhov State Institute of Measures and Measuring Instruments (KhGIMIP), and the Sverdlovsk branch of the VNIIM.

Highly qualified specialists from industrial concerns and construction and design enterprises interested in the results of investigations and leading scientists from a number of research institutes and colleges took part in the work of Commissions of Experts which were created for the purpose of evaluating the investigations performed and in the discussions held at the sessions of the Council of Experts.

The Council of Experts offered a scientificotechnical evaluation of the obtained results, indicated ways of introducing these results in the national economy and, where necessary, indicated the directions of further development of respective investigations.

The majority of works considered were on a high scientific level and represented a valuable contribution to the development of metrology and measurement techniques in our country.

As a result of investigations performed by the Sverdlovsk Branch of VNIIM on exact measurements of large direct currents, the method of parallel connection of shunts with the introduction of balancing resistors between the voltage terminals to be connected was applied for the first time, which, in contrast to the method of compensating the magnetic fields, eliminated the influence of external magnetic fields which can attain considerable intensities if large currents are measured, and secures the necessary accuracy in current measurements under operating conditions. For the certification of fixed shunts in mercury rectifier circuits, investigations were performed on a reaction current divider with a special demountable magnetic circuit which made it possible to check the shunts with errors not exceeding ±0.2%, and without breaking the current circuit. A method of certifying shunts in laboratories was developed, whereby it was possible to obtain more accurate results. The method and the equipment developed as a result of the performed investigations provided, for the first time, the possibility of testing 70-ka dc transformers under operating conditions, of detecting sources of error, and of recommending ways for the improvement of accuracy in testing. The Council recognized the necessity for continuing the research with the aim of still further improving the accuracy in testing class 0.5 transformers produced by industry, and for increasing the range of direct-current measurements to 150-200 ka.

Having considered the results of the work performed by VNIIFTRI on the design of high-quality quartz resonators for time and frequency standards, the Council expressed the opinion that the developed high-Q (up to $17.5 \cdot 10^6$) quartz resonators surpassed similar resonators of foreign make.* Having approved this work, the Council recommended further studies of aging and stability of resonators, of their resistance to vibrations, and of the development of industrial technology for the production of high-Q resonators.

The Council noted the great importance and the practical value of methods and equipment for dc testing of high-resistance standards and of equipment for the measurement of large resistors, which were developed by

*See A.G. Smagin, Izmeritel'naya Tekhnika 1, 1957.

VNIIM. As a result of the performed investigations, a method and a set of instruments consisting of the measuring device and standard resistors were developed, which provided the possibility of performing resistance measurements in a wide range (up to 10^{14} ohm) with errors not exceeding 0.5-1%. The method developed and the equipment will be of practical use in the institutes of the Committee and in a number of other organizations.*

Scientific-research work performed by KhGIMIP and VNIIM concerning the reproduction of temperature scales by the objective method is of great scientific and practical value. These investigations are of great importance in metrology practice and in work on the improvement of measurement accuracy in industry. The objective spectropyrometric device SPK-1, which was developed as a result of the performed investigations, will provide the possibility of substantially increasing the accuracy in calibrating temperature lamps with respect to brightness and luminosity temperatures.**

Recognizing the necessity for continuing work on the improvement of equipment for standardization work in the field of brightness and color pyrometry, including the extrapolation of high-temperature scales, the Council emphasized the necessity for broadening the used portion of the spectrum toward the visible short-wave and the near infrared regions, and the development of electronic systems, for the direct measurement of spectral ratios.

Methods and equipment for testing inductance standards from 0.001 to 10 h and capacitances from 100 $\mu\mu$f to 10 μf at 50 cps have been developed as a result of scientific-research and experimental work performed in VNIIM. The method and the equipment are of scientific value and of considerable practical interest, as they provide the possibility of measuring inductances and capacitances in an often used frequency range with an accuracy entirely satisfactory for practical purposes.

The scientific research work performed in KhGIMIP on the development of a method for temperature measurements with respect to infrared radiation is of great scientific and practical interest. This work represents the first stage in important and valuable investigations in the field of infrared pyrometry. Objective pyrometric systems operating in the near infrared region of the spectrum provide a possibility of extending the temperature measurement range into the region of temperatures below 700°C (practically, to 250-300°C), i.e., into the region where the pyrometers operating in the visible region of the spectrum cannot be used. On the other hand, infrared pyrometry permits a better use of the radiation flux for the control of the majority of modern technological processes. This follows from the law of spectral distribution of radiation energy. The isothermic curves of spectral distribution of energetic blackbody brightness shows that, up to temperatures of the order of 3000°C, more than 90% of the total radiation energy belongs to the near infrared region of the spectrum. In the past few years, semiconductor devices highly sensitive to near infrared radiation have been developed, and lead sulfide photoresistors have been successfully applied in pyrometers operating in the infrared region of the spectrum. This is the technological prerequisite for the practical application of infrared pyrometry systems. At the present time, laboratory and industrial infrared pyrometry systems are under development. This emphasizes the importance of investigations performed in KhGIMIP and the usefulness of work on the improvement of standard spectropyrometers as well as on the development of a device of the SPK type for calibrating temperature lamps in the near infrared region.

After studying the question of scientific-research work on the development of methods and equipment for testing interference meters in the 400 Mc frequency range and after considering the research work performed, and the methods and equipment for testing 20-Mc interference meters developed by VNIIFTRI, the Council expressed the opinion that the question considered and the investigations performed by VNIIFTRI are of great importance, since the problem of eliminating industrial radio interference assumes an ever-increasing importance in connection with the development, on the one hand, of a network of radio and television receivers and an increase in their sensitivity, and, on the other hand, in connection with the growing stock of electric appliances which are the source of radio interferences.

The methods and equipment for testing 20-Mc interference meters, which were developed by VNIIFTRI, facilitated the detection of a number of basic deficiencies of interference meters. As a result of state-sponsored tests performed on a number of interference meter models (IP-14, IP-26, IP-12M, and IP-12-2M), the IP-14 and the IP-12M meters were rejected as obsolete. VNIIFTRI worked out a set of systematic instructions for testing interference meters and developed the IG-1 pulse generator which is a source of pulsed voltage with standard spectral density in the 20-Mc range. The use of pulse generators producing steep pulse fronts is of great practical

*See G.F. Pankratov and T.B. Rozhdestvenskaya, Izmeritel'naya Tekhnika 5, 1958.

**See V.A. Kovalevskii, G.L. Iosel'son and V.V. Kandyba, Izmeritel'naya Tekhnika 2, 1956.

importance. Recognizing the positive results of the work performed by VNIIFTRI in this field, the Council emphasized the necessity for speeding up the development of instruments for testing interference meters for the range of frequencies above 20 Mc and for extending the frequency range in testing interference meters to 1000 Mc in the near future. The Council also recommended the development in the next 2-3 years, of All-Union State Standards for Measuring Equipment and proposed to entrust the supervision of this work to the Interdepartmental Commission for Radio Frequencies of the Ministry of Communications of the USSR, assigning this work to VNIIFTRI, the State Radio Inspection of the Ministry of Communications of the USSR, and other organizations.

Another important problem of the national economy is the provision of unique standards for the measurement of moisture in grain, as the moisture content in grain is one of the basic characteristics in establishing the quantity and quality of grain in all stages of breadmaking. This fact lent great importance to scientific-research work on the development of standard methods of measuring the moisture content in grain, which was performed by VNIIK and the All-Union Scientific-Research Institute for Grain (VNIIZ).

An important part of this work was the study of the influence of biochemical properties of grain in the process of dehydration on the measurement of moisture content in grain, the influence of temperature conditions in drying on the degree of dehydration, and the study of dehydration and heating kinetics. These investigations formed the basis for the development of methods of measuring the moisture content in grain and for the determination of dehydration conditions securing the greatest possible degree of dehydration without noticeable biological changes in grain.

The developed standard methods are based on the determination of the moisture content according to the dry residue after drying under certain given conditions. Two methods have been developed on this basis (in the VNIIK – the method of drying by heating in vacuum and in the VNIIZ – the method of warm-air drying at atmospheric pressure) and the appropriate equipment has been designed.

The Council remarked that the investigations performed by VNIIK and VNIIZ are of scientific and practical value. As a result of the study and comparative evaluation of the methods and equipment proposed, it was recommended that the vacuum-heating method of drying and the corresponding equipment developed by VNIIK be accepted as the standard method of measuring the moisture content in grain, as this method and the corresponding equipment are characterized by a somewhat greater accuracy in comparison with the warm-air method, securing a greater reliability in reproducing and maintaining the established drying conditions and, consequently, a better identity of measurement conditions, which was of decisive importance in deciding which equipment should be accepted as the standard one.

The Council recommended that work be continued on the development of a simpler equipment for the measurement of moisture content in grain, which would be suitable as standard equipment for the calibration and testing of working equipment, and it also recommended the development of a testing scheme for moisture-content measurements in grain, in correspondence with practical requirements and basic metrological standards, determining the mutual interdependence of separate elements in the testing scheme.

Apart from the scientific-research work mentioned above performed on a sufficiently high scientific level and being of value in metrological and measurement practice in industrial enterprises, some of the scientific-research works reviewed by the Council did not provide a full solution of the problems involved and were considered as unsatisfactory.

Thus, in the expert opinion offered on the paper "Investigation of Methods for the Transmission of Linear Dimensions in Automatic Lines and Individual Highly Accurate Machine Tools" prepared by VNIIM, it was established that this work did not solve the assigned task. The first part of the report submitted for expert opinion contains an incomplete survey of the well-known methods and control devices, the data on which have been published earlier. The second part of the paper, containing the results of investigations of the diffraction and interference methods of measuring the pitch of lead screws, considers an individual case only – the measurement of the screw pitch, and, moreover, the method has not been sufficiently developed for practical purposes.

Considering the importance of scientific research in the field of measurement methods in automatic assembly lines and, in particular, of the task assigned, the Council recommended that VNIIM continue work in this direction, together with organizations working in the automation field, and also formulate the task of further metrological investigations in the field of measurements in automatized production.

After considering the paper "Design of a Standard Device for Testing Gamma-Radiation Dosimeters," which was prepared by VNIIM, the Council decided that the quality of preparative and experimental work and of reports in these investigations was not satisfactory.

Emphasizing the importance of metrological investigations in the field of dosimetric measurements and the necessity for basic research in this field, the Council decided that the pace of investigations performed by VNIIM in this field of measurements was unsatisfactory.

The given examples indicate the necessity for raising the scientific level of investigations and of experimental work in a number of laboratories in institutes of the Committee and for improving the suspension of scientific-research work on the part of laboratory directors, scientific councils, and management of institutes.

MEASURES AND MEASURING INSTRUMENTS APPROVED BY THE COMMITTEE ACCORDING TO STATE INSPECTION RESULTS AND AUTHORIZED FOR USE IN THE USSR

(According to records for March-April, 1959)

Lever resistance box, Model MSR-58, produced by the L'vov Council of National Economy. State Register No. 1235-59.

Panel microammeter, Model M-216, produced by the Omsk Council of National Economy. State Register No. 1236-59.

Panel microammeter, Model M-220, produced by the Omsk Council of National Economy. State Register No. 1237-59.

Portable electronic voltmeter, Model F-505, produced by the Kiev Council of National Economy. State Register No. 1238-59.

Hardness ball-gauge, Model TSh-2, produced by the Ivanovo Council of National Economy. State Register No. 1239-59.

Thermometer for oil separators, Model TP-10, produced by the Moscow Regional Council of National Economy. State Register No. 1240-59.

Ordinary dc bridge, Model R-316, produced by the Krasnodar Council of National Economy. State Register No. 1241-59.

Portable calibrated shunt, Model R114 and R114/1, produced by the Leningrad Council of National Economy. State Register No. 1242-59.

Small-size vibration frequency meter, Model V80, produced by the White Russian Council of National Economy. State Register No. 1243-59.

Small-size vibration frequency meter, Model V81, produced by the White Russian Council of National Economy. State Register No. 1244-59.

Hardness gauge, Model TK-2, produced by the Ivanovo Council of National Economy. State Register No. 1245-59.

Standard extension class III dynamometer, Models DR-0 and DR-0.5, produced by the Latvian Council of National Economy. State Register No. 1246-59.

Vertical optical length meter, Model IZV-21, produced by the Leningrad Council of National Economy. State Register No. 1247-59.

Dioptrimeter, Model DO-2, produced by the Moscow Regional Council of National Economy. State Register No. 1248-59.

Photoelectric colorimeter-nephelometer, Model FEK-N-57, produced by the Moscow Regional Council of National Economy. State Register No. 1249-59.

Nonreactive resistance box, Model R-517, produced by the Kiev Council of National Economy. State Register No. 1250-59.

Semi-microanalytic scales, Model VM-20, produced by the Leningrad Council of National Economy. State Register No. 1251-59.

SIGNIFICANCE OF ABBREVIATIONS MOST FREQUENTLY ENCOUNTERED IN SOVIET TECHNICAL PERIODICALS

AN SSSR	*Academy of Sciences, USSR*
FIAN	*Physics Institute, Academy of Sciences USSR*
GITI	*State Scientific and Technical Press*
GITTL	*State Press for Technical and Theoretical Literature*
GOI	*State Optical Institute*
GONTI	*State United Scientific and Technical Press*
Gosénergoizdat	*State Power Press*
Gosfizkhimizdat	*State Physical Chemistry Press*
Goskhimizdat	*State Chemistry Press*
GOST	*All-Union State Standard*
Gostekhizdat	*State Technical Press*
GTTI	*State Technical and Theoretical Press*
IAT	*Institute of Automation and Remote Control*
IF KhI	*Institute of Physical Chemistry Research*
IFP	*Institute of Physical Problems*
IL	*Foreign Literature Press*
IPF	*Institute of Applied Physics*
IPM	*Institute of Applied Mathematics*
IREA	*Institute of Chemical Reagents*
ISN (Izd. Sov. Nauk)	*Soviet Science Press*
IYap	*Institute of Nuclear Studies*
Izd	*Press (publishing house)*
LÉTI	*Leningrad Electrotechnical Institute*
LFTI	*Leningrad Institute of Physics and Technology*
LIM	*Leningrad Institute of Metals*
LITMiO	*Leningrad Institute of Precision Instruments and Optics*
Mashgiz	*State Scientific-Technical Press for Machine Construction Literature*
MGU	*Moscow State University*
Metallurgizdat	*Metallurgy Press*
MOPI	*Moscow Regional Pedagogical Institute*
NIAFIZ	*Scientific Research Association for Physics*
NIFI	*Scientific Research Institute of Physics*
NIIMM	*Scientific Research Institute of Mathematics and Mechanics*
NIKFI	*Scientific Institute of Motion Picture Photography*
NKTM	*People's Commissariat of the Heavy Machinery Industry*
Obrongiz	*State Press of the Defense Industry*
OIYaI	*Joint Institute of Nuclear Studies*
ONTI	*United Scientific and Technical Press*
OTI	*Division of Technical Information*
OTN	*Division of Technical Science*
RIAN	*Radium Institute, Academy of Sciences of the USSR*
SPB	*All-Union Special Planning Office*
Stroiizdat	*Construction Press*
URALFTI	*Ural Institute of Physics and Technology*
TsNIITMASh	*Central Scientific Research Institute of Technology and Machinery*
VNIIM	*All-Union Scientific Research Institute of Metrology*

NOTE: Abbreviations not on this list and not explained in the translation have been transliterated, no further information about their significance being available to us — *Publisher.*

Publication of a "Soviet Instrumentation and Control Translation Series" by the Instrument Society of America has been made possible by a grant in aid from the National Science Foundation, with additional assistance from the National Bureau of Standards for the journal *Measurement Techniques.*

Subscription rates have been set at modest levels to permit widest possible distribution of these translated journals.

The Series now includes four important Soviet instrumentation and control journals. The journals included in the Series, and the subscription rates for the translations, are as follows:

MEASUREMENT TECHNIQUES – *Izmeritel'naya Tekhnika*

Russian original published by the Committee of Standards, Measures, and Measuring Instruments of the Council of Ministers, USSR. The articles in this journal are of interest to all who are engaged in the study and application of fundamental measurements. Both 1958 (bimonthly) and 1959 (monthly) available.

Per year (12 issues) starting with 1959, No. 1

General:	United States and Canada	$25.00
	Elsewhere	28.00
Libraries of nonprofit academic institutions:		
	United States and Canada	$12.50
	Elsewhere	15.50

INSTRUMENTS AND EXPERIMENTAL TECHNIQUES
Pribory i Tekhnika Éksperimenta

Russian original published by the Academy of Sciences, USSR. The articles in this journal relate to the function, construction, application, and operation of instruments in various fields of experimentation. 1958 and 1959 issues available.

Per year (6 issues) starting with 1959, No. 1

General:	United States and Canada	$25.00
	Elsewhere	28.00
Libraries of nonprofit academic institutions:		
	United States and Canada	$12.50
	Elsewhere	15.50

AUTOMATION AND REMOTE CONTROL – *Avtomatika i Telemekhanika*

Russian original published by the Institute of Automation and Remote Control of the Academy of Sciences, USSR. The articles are concerned with analysis of all phases of automatic control theory and techniques. 1957, 1958, and 1959 issues available.

Per year (12 issues) starting with Vol. 20, No. 1

General:	United States and Canada	$35.00
	Elsewhere	38.00
Libraries of nonprofit academic institutions:		
	United States and Canada	$17.50
	Elsewhere	20.50

INDUSTRIAL LABORATORY – *Zavodskaya Laboratoriya*

Russian original published by the Ministry of Light Metals, USSR. The articles in this journal relate to instrumentation for analytical chemistry and to physical and mechanical methods of materials research and testing. 1958 and 1959 issues available.

Per year (12 issues) starting with Vol. 25, No. 1

General:	United States and Canada	$35.00
	Elsewhere	38.00
Libraries of nonprofit academic institutions:		
	United States and Canada	$17.50
	Elsewhere	20.50

Single issues of all four journals, to everyone, each . . . $6.00

Prices on 1957, 1958 issues available upon request

SPECIAL SUBSCRIPTION OFFER:

One year's subscription to all four journals of the 1959 Series, as above listed:

General:	United States and Canada	$110.00
	Elsewhere	122.00
Libraries of nonprofit academic institutions:		
	United States and Canada	$ 55.00
	Elsewhere	67.00

Subscriptions should be addressed to:

Instrument Society of America
313 Sixth Avenue
Pittsburgh 22, Penna.

#482